Electrical Engineering

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American Institute of Electrical Engineers

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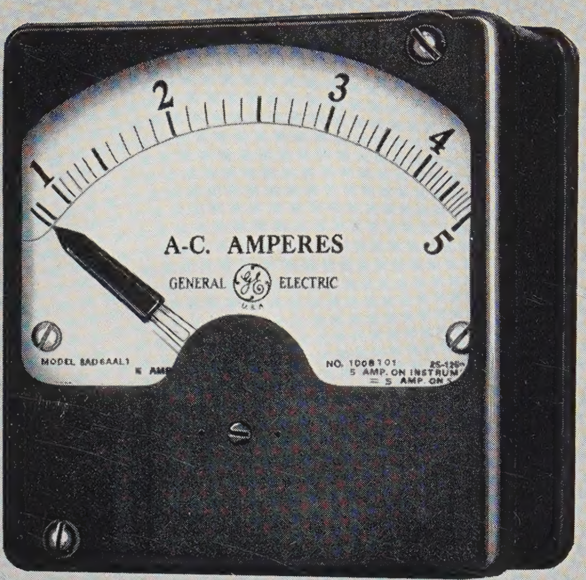

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This Month—

Front Cover

Esplanade of State of the Texas Centennial Central Exposition, Dallas, at night. The exposition is expected to be one of the principal attractions to those attending the Institute's forthcoming South West District meeting.

Special Articles

AIEE Papers

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Discussions

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Conductor Vibration

Illumination

Power Transmission and Distribution

News 1153

In This Issue—

ILLUMINATION is featured in 3 papers in this issue. One paper comprises a report of progress in this field during the past 4 years prepared by the AIEE committee on production and application of light. This report deals primarily with light sources and luminaires (*pages 1111–20*). A second paper outlines today's trends in lighting, and on the basis of those trends presents some predictions for the future. This paper deals principally with modern applications of light and includes illustrations of some outstanding examples of modern illumination (*pages 1100–10*). A third paper, which describes the electrical features of the Texas Centennial Central Exposition at Dallas, deals at some length with the spectacular illumination effects achieved at that exposition (*pages 1060–74*). In addition to the 3 papers on illumination included in this issue, 2 additional papers on this subject are scheduled for publication in an early issue. These 2 papers deal respectively with high-efficiency gaseous-conduction lamps, and high-intensity mercury-arc lamps.

ACCELERATED aging tests have been found to be of great value in predetermining the stability of the insulation of high-voltage cables. Such tests are particularly valuable for predetermining the effectiveness of changes in manufacturing methods, in insulating materials, or in the thickness of insulation. A series of tests on samples of 750,000-circular mil cable of recent manufacture representing a wide range of quality, conducted by a large midwestern power company that has pioneered in the development of such tests, has revealed significant information (*pages 1074–82*).

THE ideal network protector fuse is one that will blow only in the event of failure of other network protective equipment, to prevent damage to the transformer, net work protector, and adjacent network mains. A new fuse comprising a combination of a fusible alloy of low melting point and copper blocks that delay the rate of temperature rise has characteristics approaching this ideal. A limited number of such fuses has been in operation on the underground network system of a large eastern power company, with quite satisfactory results (*pages 1096–9*).

PROTECTIVE relay systems cannot be installed once and for all and then be expected to function perfectly under all circumstances. Long experience invariably will demonstrate that the original installations are inadequate to comply with advanced conceptions of desirable relay performance and will point the way to necessary additions and improvements. This is one of the conclusions reached in a paper outlining the practical operating experiences with a modern protective relay system over a 5-year period (*pages 1130–6*).

AUTOMATIC voltage regulating equipment installed on distribution circuits at points remote from a substation will enable long distribution circuits to be loaded to their full current-carrying capacities unhampered by the limitation of voltage regulation. Tests made by a typical eastern power company have demonstrated the practicability of this form of regulation, and its field of application is indicated by economic comparison with other methods of maintaining voltage within required limits (*pages 1083–96*).

CARRIER current relaying combined with rapid reclosure of circuit breakers represents the solution to a problem faced by a southern power company in which it became necessary to improve continuity of service to industrial plants supplied over a 110-kv 120-mile line. This line, which functions in the dual capacity of trunk interconnection and load feeder, has been equipped in this manner to clear faults and restore service in approximately one second (*pages 1120–9*).

NEW chairmen have been appointed for many of the Institute's general and technical committees to serve during the year 1936–37. These chairmen are being introduced to the membership of the Institute through the "Personals" columns of ELECTRICAL ENGINEERING. The first group appears in this issue (*pages 1157–9*); others will follow in subsequent issues.

DALLAS, Texas, will be host to the Institute's South West District, October 26–28. One of the principal attractions for those attending will be the Texas Centennial Central Exposition now being held in that city. The final announcement concerning this meeting appears in the news section of this issue (*page 1153*).

DISCUSSIONS in this issue comprise the first group on 1936 summer convention papers to be published (*pages 1136–52*). Other discussions on summer convention papers will be published in future issues as they become available.

CORRECTION. The illustrations on pages 1018 and 1019 of the September issue of ELECTRICAL ENGINEERING should be interchanged; in other words, the diagram on page 1018 is figure 5, and that on page 1019 is figure 4.

A GOAL of 2,000 applications for membership by May 1, 1937 has been set by the Institute's national membership committee. The co-operation of every member of the Institute is solicited in order that this goal may be reached (*page 1153*).

COMMITTEES already are busy formulating plans for the Institute's 1937 winter convention to be held in New York, January 25–29. Details of the technical sessions and other features will appear in subsequent issues.

EAST TENNESSEE SECTION of the Institute recently was organized by a group of leading members in that area. This brings the total number of AIEE Sections up to 62 (*page 1153*).

LETTERS on a variety of subjects continue to be received by the editor. Contributions to this department on any paper or article appearing in ELECTRICAL ENGINEERING are solicited (*pages 1155–6*).

—A Message From the President

Text of an address delivered June 23, 1936, at the annual conference of officers, delegates and members held in connection with the summer convention at Pasadena, Calif.

IN 1921 I attended my first Institute convention, as a delegate from the Cleveland Section. This was a joint national and Pacific Coast convention held in Salt Lake City. Of all the meetings at the convention, the Section delegates' conference was that which most interested me and roused my enthusiasm. For the first time I realized that the Cleveland Section, and I as its delegate, played a vital and important part in the conduct of the affairs of the Institute. In my report to the Section the following fall, I endeavored to carry to them something of the enthusiasm and inspiration which I had received, and I hope that each one of you will likewise transmit to your Sections the fine spirit of enthusiasm and achievement so evident in this Section delegates conference held during the joint summer and Pacific Coast convention, meeting in Pasadena.

Our organization is international in its scope. The opinion of an individual in India or Hawaii merits as much consideration as the opinion of an individual in New York or Cleveland. From the practical viewpoint, the greater part of our activities are carried on in New York since it is there that our Headquarters are located, in the Engineering Societies Building. However, it is indeed fortunate that at least once every year each Section is represented in such a conference as this. I wish that practical consideration permitted these conferences at more frequent intervals. It is the hope of the board of directors and the headquarters staff that, at frequent intervals throughout the year, each Section will give us the benefit of its suggestions through correspondence.

Recommendations that are made, and which this body has felt to be of sufficient merit to crystallize by an affirmative motion, will be very carefully considered by the board and, if consistent with the general welfare of the whole organization, will be approved. If, in the opinion of the board, the suggestions seem inconsistent with the general welfare, you will be advised of the reasons for the board's decision. Both you and the board have one common interest: the advancing of the welfare of the American Institute of Electrical Engineers.

The carrying out of the purposes of our organization is largely through technical and general committees. As far as is consistent with the success of the committee work, it is our desire that these committees should be representative of the whole organization. These committees will be appointed and presented to the board within the next 6 to 8 weeks, and I ask that you carry back to your Sections my request for suggestions as to appointments on these various committees. Committee meetings are essential, and geographical remoteness is recognized as a handicap to attendance at these meetings. However, participation by mail, particularly on technical committees, leads to very excellent results; as evidenced by the fine work performed by the Pacific Coast members on many technical committees.

It is desirable to have our technical program widely representative of all industries, interests, and geographical localities, and we appeal to you and your Section to aid us in achieving this result. I suggest that each Section's meetings and papers committee assume the responsibility of securing at least one paper each year for submission to the national technical program committee. During the past year at least 4 papers have been presented by members of the Cleveland Section. We challenge each Section to equal or surpass this record. The New York, Pittsburgh, and Schenectady Sections have very largely contributed to the technical program, and we are counting on them to continue their fine record. Baltimore, Chicago, Lehigh Valley, Los Angeles, and many others have a record even better than Cleveland, but we repeat the request; at least one national paper from each Section.

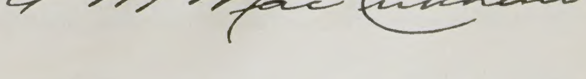
This year's report of the membership committee has been an inspiration to all of us. While the securing of members is not our primary objective—rather, the advancement of the theory and practice of electrical engineering and of the allied arts and sciences, and the maintenance of a high professional standing among our members—still, a healthy growth in membership is an evidence of success, and unquestionably increases our ability to carry out our fundamental purposes. I have looked upon membership in our organization as a privilege worthy of the consideration of every electrical engineer. Our membership activities should be in the direction of calling attention to this privilege, of which some in the profession may not be taking advantage. From the standpoint of the individual nonmember electrical engineer, it is undoubtedly his duty to support that organization which advances the standing of his profession. Often it is but necessary to call this to his attention and he recognizes the correctness of this view.

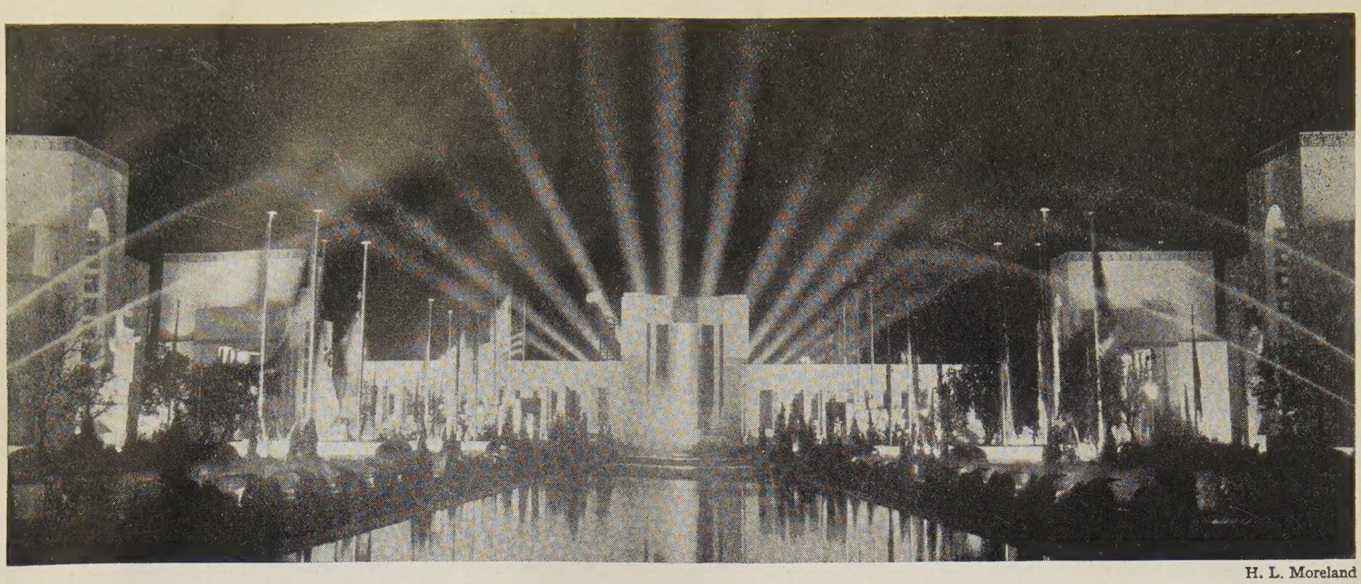
To the Section delegates I wish to emphasize the importance of the student Branches. May I ask your indulgence in again referring to Cleveland? At Case School of Applied Science there are 46 men eligible for membership in the Case Student Branch of the AIEE, and there are exactly 46 members. At the annual dinner meeting in May there were 46 student members present to welcome President Meyer. Each year there is a joint meeting of the student Branch with the Section, and part of the meeting presided over by the student Branch chairman. It is not possible to overemphasize the importance of the student Branch activity.

I desire to emphasize the movement toward small group technical meetings, of which 2 were held in Cleveland last year; one on motors, and one on control. Their success was quite astounding. In each case the attendance approached that of a regular Section meeting. Such meetings offer the opportunity for round-table discussion participated in by many. Each member of the Institute benefits from the organization in direct proportion to that which he contributes to it.

One of the most delightful phases of Institute activity is the personal acquaintances and friendships which develop among its members. While I have not seen Mr. John Fisken since the Salt Lake Convention in 1921, I feel that we are intimate acquaintances.

During the year I hope to visit many of your Sections, and look forward to the opportunity of meeting your associates in the Section activities. I look forward to meeting your successors at Milwaukee next June. It has, indeed, been a pleasure to meet with you and profit by your discussions. I shall be a much better President than though I had missed this opportunity. This conference has undoubtedly been the best that we have ever had, and may it be the poorest that we ever will have.





H. L. Moreland

Fig. 1. The Esplanade of State at night with the Hall of the State of Texas and the searchlight scintillator in the background

Electrical Features of the Texas Centennial Central Exposition

The one-hundredth birthday of the state of Texas has been the occasion for the construction of a great exposition at Dallas. The success of such an exposition is dependent upon the electrical illumination, power, sound equipment, and signal and communication systems. This paper outlines the electrical features of the Dallas exposition.

By
JOHN FIES
ASSOCIATE AIEE

Texas Centennial Central Exposition, Dallas

CENTURIES AGO, long before the advent of useful electricity, fairs provided a time of year for country folks and merchants to travel distances, under special protection not always assured at other times of the year. These fairs provided a place for public gatherings, markets, and festivals.

The first large exhibition of importance to industry was the Crystal Palace fair in London in 1851. Here the extensive use of glass in the walls of buildings is in direct contrast with the windowless walls of recent expositions. It is reported[1] that the Paris exposition of 1867 attempted to entertain visitors at night by the extensive use of gas and oil lamps but that attendance after dark was a complete failure even though special evening attractions were provided. The Dallas exposition, because of its electrical illumination (figure 1) has been called a "night fair" just as the more recent expositions have been exceedingly interesting at night.

Incandescent lighting was used on a relatively large scale at the electrical exposition at the Palais de l'Industrie at Paris in 1881. The telephone also contributed to the success of this exposition. Arc lighting was prevalent and the exposition was kept open successfully at night. The Cotton exposition in New Orleans in 1884 specified electricity[1] exclusively as the luminant. The great Paris exposition in 1889 used electrical illumination extensively and created an illuminated fountain.

Electricity for expositions became of age at the Columbian exposition in Chicago in 1893, where were utilized electrical illumination, both interior and exterior, illuminated fountains, large searchlights, electric power machinery, and motor-operated exhibits, elevators, and transportation. There were telephone systems, telegraph services, and fire and police signal systems. Here searchlights were used occasionally to illuminate statuary and building exteriors. It has been written (1894) that electricity at the Columbian exposition "dissolved much of the mystery that has pervaded its domain; it brought

A paper recommended for publication by the AIEE committee on production and application of light, and scheduled for discussion at the AIEE South West District meeting, Dallas, Texas, October 26–28, 1936. Manuscript submitted August 26, 1936; released for publication August 27, 1936.

The author wishes to express appreciation to C. M. Cutler, illumination engineer for the Texas Centennial Central Exposition, and to his assistant, W. E. Folsom, for their suggestions and criticisms with respect to the parts of this paper dealing with illumination elements. There are many others who have assisted materially in the preparation of this paper and to whom the author is indebted.

electricity to the people in the light of a servant, not an awful master."[1]

Incandescent floodlighting of exterior surfaces of exposition buildings was applied extensively at the Panama-Pacific exposition in San Francisco in 1915 and to this was added exterior mobile color lighting at the Barcelona exposition in Spain in 1929. "A Century of Progress" exposition in Chicago in 1933–34 contributed many applications of architectural lighting elements, many applications of gaseous-conductor tubing, and a coverage of the exposition grounds by public-address speakers.

The Dallas Exposition

The Dallas exposition (figure 2) was built within an area of approximately 175 acres, part of which had been the nucleus of the annual State Fair of Texas since 1886. A feature of this exposition is the degree of permanence of the principal buildings. Part of the area will be used for future Southwestern expositions and the part containing the new museum buildings will become a permanent city park. This degree of permanence influenced much of the electrical construction, particularly the fountains, floodlighting, and the main distribution system.

All electrical and illumination elements were considered at the time the original budget for the exposition was prepared and ample funds for these elements were provided according to estimates based upon the proposed plans. Full co-operation existed between the electrical, architectural, and other departments during all the stages of planning, thereby assuring particularly the unity existing at this fair between the illumination, architecture, and landscape elements.

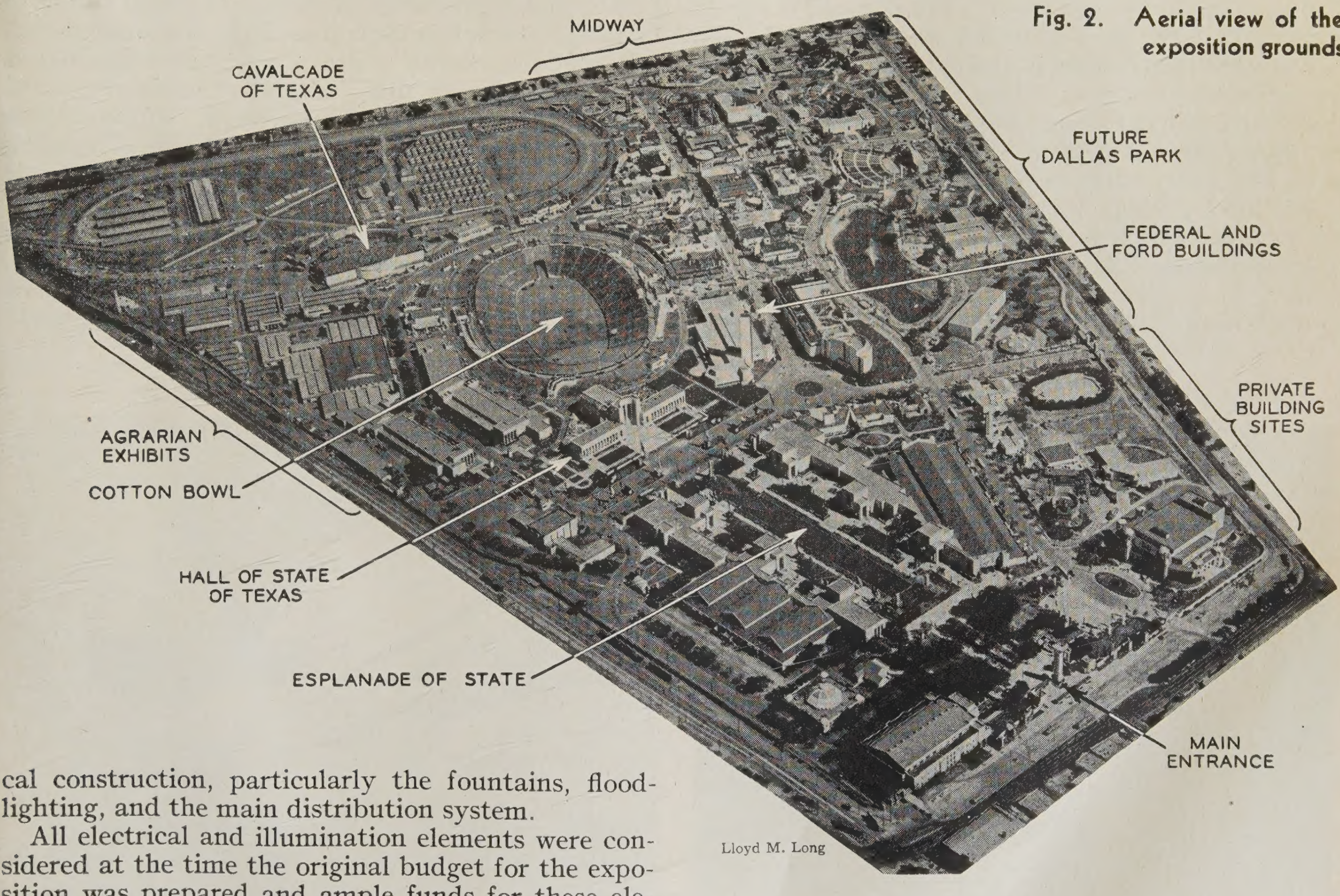


Fig. 2. Aerial view of the exposition grounds

Illumination of Interiors[2]

A characteristic of the Dallas exposition, like other recent expositions, is the absence of windows and natural lighting within most of the buildings. Artificial lighting is particularly suitable for expositions because each exhibit is primarily a show place for the display of wares, products, and other items of interest; or for the display of information pertaining to the manufacture or use of these things; or for the display of educational subjects. Such displays when properly arranged under controlled artificial light are more effective than when arranged under a combination of artificial light and varying natural light.

Exposition building interiors are particularly interesting when there are various types (figure 3) and styles of interior decoration and illumination. The interiors at this exposition, however, can be classified roughly as follows:

First, there are the permanent interiors, which are found particularly in the Hall of the State of Texas and in the City of Dallas buildings consisting of the museum of fine arts, the museum of natural history, the aquarium, the domestic arts and horticultural museums, the combination fire, police, and emergency hospital station, and in the interior of the band shell. The State building was designed by an architectural association and the City buildings were designed by local architects under the supervision of

the park board architect. Although interiors and interior-illumination elements within these buildings are representative of the individual tastes of the several architects, the interior-illumination elements and methods are interesting and are treated according to accepted practices for the respective type of building. Illumination elements within such buildings definitely have a place in interior design. The luminaires are in various styles and costliness; they are ornate in bronze and glass or simple enclosing elements as required to be a proportional and fitting part of the respective interiors of marble, murals, paintings, statuary, or plaster. The natural-history museum in particular requires extensive lighting for show cases and the aquarium requires tank lighting.

Second, there are the semipermanent interiors, which are to be found in the exhibit buildings constructed by the exposition corporation under the supervision of the exposition's architect. These exhibit-building interiors may be divided into halls, corridors, and exhibit spaces. Halls, as considered here, are spacious, have ceilings varying in height up to 35 feet, and are often specially decorated. These halls generally are lighted by indirect cove lights with or without reflectors, or by parabolic reflectors of several different finishes, recessed into the ceilings and provided with spill rings. For decorative effects some halls have been provided with lighted vertical coves, with lighted panels and grilles, and with gaseous-conductor tubing. Lines and designs of "lumiline" incandescent lamps have been used effectively for decorative purposes. Corridors, as considered here, are aisle spaces between exhibit spaces. Corridors have ceilings from 12 to 16 feet high, lighted by indirect light from troughs located at either side of the corridors. These lighting troughs, which vary from 9 to 12 feet in height, have been designed to serve as sign shelfs for silhouetted letters. Exhibit spaces which are located in exhibit halls ordinarily depend upon the general lighting of these halls for base lighting. Most of the exhibit spaces, however, have their own ceilings which vary from 12 to 16 feet in height and these ceilings are provided with base lighting elements. The exposition standard for base lighting in exhibit spaces consists of recessed reflectors of several different finishes, but principally "alzak" aluminum with silvered-bowl and white-bowl lamps to give good distribution without glare. Exhibitors have been permitted to supplement base lighting with additional illumination as required, provided that the regulations of the exposition corporation applicable to glare, color, and type are observed. The illuminating elements within the exposition corporation's halls and corridors are almost entirely of economical architectural types. A consideration in the selection of such lighting was standardization and quick procurement of materials.

Third, there are the interiors that are to be found in buildings constructed by private exhibitors and concessionaires. The designers of private buildings were allowed to illuminate and decorate the interiors according to their own desires and imaginations, subject, however, to some guidance and control by the exposition corporation. Illumination in private buildings includes artificial skylights, panel and cove lighting, indirect lighting from large and small pedestals, and the extensive use of suspended luminaires of many types and sizes. Standard luminaires have been used through the Midway area. Incandescent lighting in the main exhibit hall of the Ford building has been supplemented by indirect mercury-vapor lighting.

There are a few elements which distinctly influence interior exposition lighting. These are cycloramas, dioramas, photo-murals, counter displays, show-case displays, show-window displays, niche displays, back-

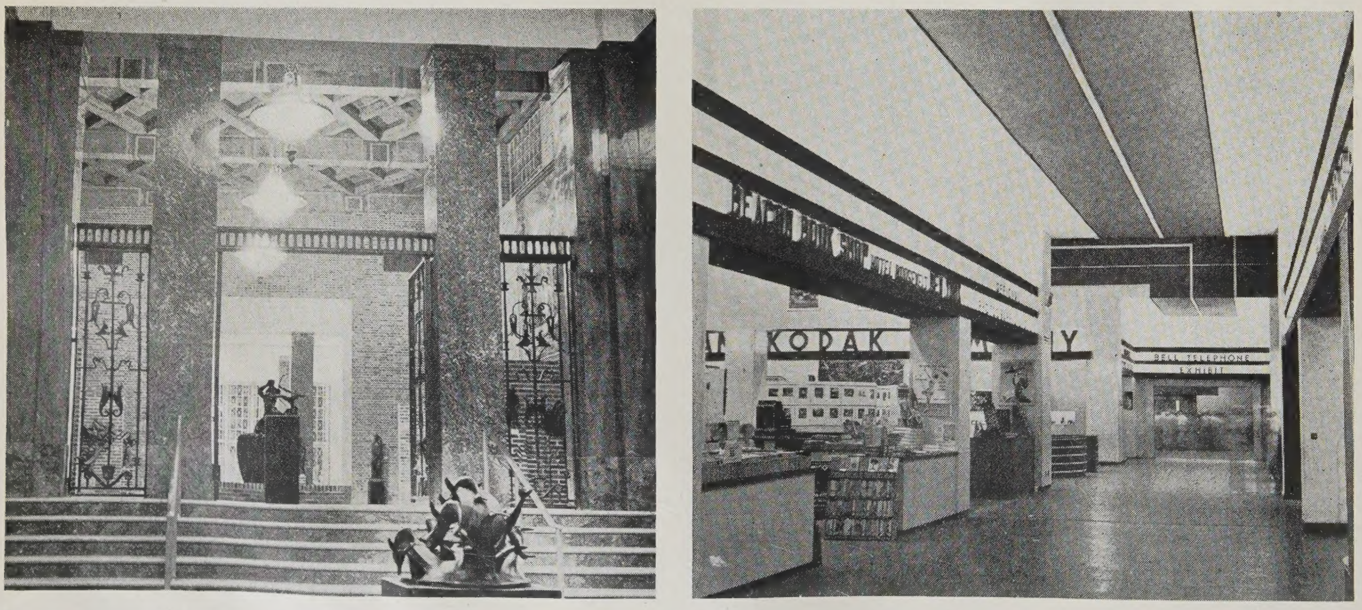
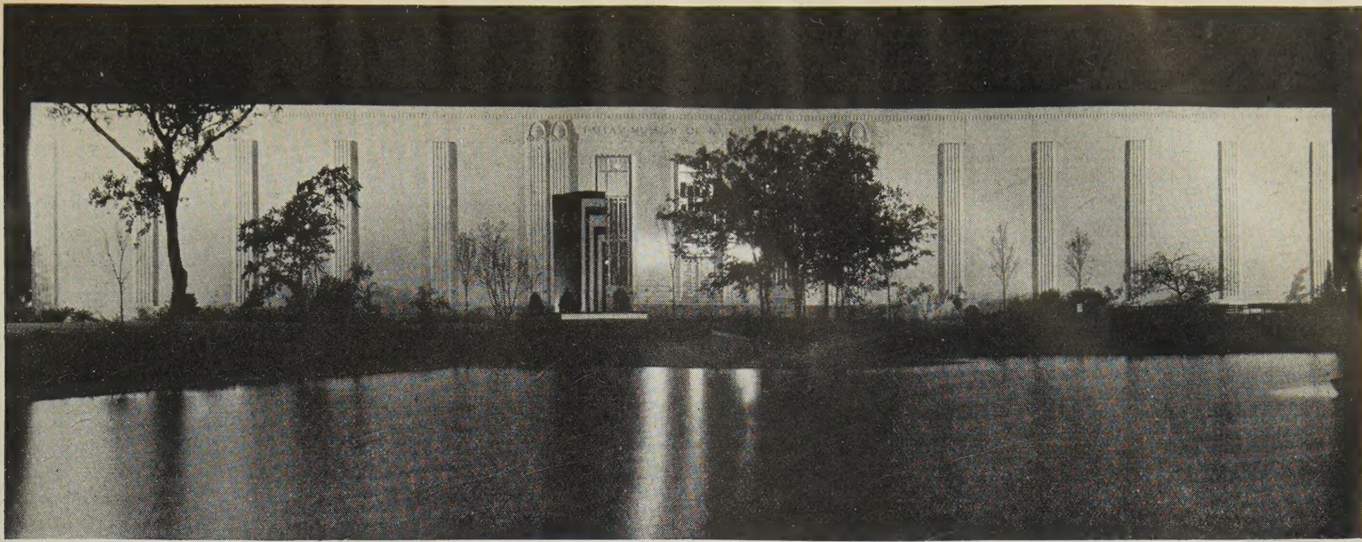


Fig. 3. The sculpture court (left) in the new fine arts museum with its special luminaires, and a typical corridor (right) in the Hall of Electricity with its sign-shelf lighting. These illustrate the extremes of types of interior illumination at the Dallas exposition



Paul R. Clegg

Fig. 4. The Dallas Museum of Natural History as seen at night from across the lagoon. Note the silhouetted trees and public-address pylon

lighted pictures, and small motion-picture screens. These elements require a proper light environment.

There are auditoriums available for public gatherings and special events, and motion picture and other theaters which have suitable lighting elements. Free theaters provided by exhibitors are very popular, particularly if air conditioned. A comfortable place to sit down and be entertained is very acceptable after hours of walking at an exposition. There are some 14 private free theaters within the exposition grounds, seating between 30 and 300 people. Nine of these are air conditioned.

Emergency lighting and properly placed exit lights and signs are very important in large exposition buildings. Fourteen of the major buildings at the Dallas exposition have been provided with emergency lighting systems. These emergency systems have been designed to keep all exit lights and a few corridor lights lighted for at least 20 minutes after the main lighting systems fail.

A summary of interior illumination shows that intensities range from 10 to 40 foot-candles and that the electrical requirements vary from 2 to 20 watts per square foot for illumination only. Representative averages are: from 10 to 30 foot-candles and from 4 to 10 watts per square foot in exhibit halls; from 8 to 12 foot-candles and from 4 to 7 watts per square foot in exhibit corridors; and from 10 to 30 foot-candles and from 2 to 12 watts per square foot in typical exhibit spaces. The total interior electrical lighting load has been estimated at approximately 4,000 kw.

Illumination of Building Exteriors[2]

Exterior surfaces of buildings and large structures are illuminated principally by floodlighting. The exceptions are the lighting of the fronts in the Midway and some decorative lighting about the exteriors of certain buildings. This latter may be by incandescent-lamp strips or clusters, either indirect or behind translucent material, or by exposed or indirect gaseous-conductor tubing, depending upon the brightness of the background.

The floodlighting of the majority of structures and particularly the exposition corporation's exhibit buildings has been accomplished by incandescent floodlights installed close to the surfaces to be lighted. Light is projected upward onto these surfaces through lenses selected to give correct beam concentration or spread as required. Floodlights have been spaced relatively close together to give even light distribution and to avoid emphasizing the irregularities of the lighted surfaces. Floodlight locations have been concealed wherever practicable by planting-boxes, by direct plantings, or in instances where the floodlights are required at levels above the ground, by placing them in lighting troughs, behind parapet walls, or in niches.

The floodlighting of permanent museum buildings has been accomplished by mounting floodlight units approximately 25 feet above the ground in housings supported by ornamental standards. These museums—built of white limestone (figure 4) and similar materials—have considerable natural beauty, hence floodlighting is by white light. The white light, projected at a distance of approximately 60 feet from 3 or 4 points about each building, gives interesting effects of light and shadows, particularly where a nearby tree is silhouetted by the white surface.

The exterior walls of the exposition corporation's main exhibit buildings are of stucco, painted with a water-mixed cement-bonding paint containing between 7 and 10 per cent of coloring matter. This produces a diffusing surface with a reflection factor of approximately 60 per cent. The result is a nonglossy neutral buff color which gives a uniformity of soft color to these buildings by daylight while at night it permits varied colors when floodlighted through lenses of red, amber, light amber, green, and blue. It is well known that floodlighting tends to reverse the shadows of certain classes of architecture and it should be pointed out that practically every

building at the Dallas exposition was designed to be floodlighted. Efforts were made not only to eliminate reversed shadows but to produce interesting night shadows and to provide means for concealing lighting equipment.

Many of the exposition corporation's main exhibit buildings have large exterior murals or colored bas-reliefs within or near the large portals to the buildings. These are lighted at night by white light, although some amber and red light is used. Murals and colored bas-reliefs when lighted at night stand out effectively, particularly if the paint pigments are such as will retain approximately their relative values under the selected light and hue.

The illumination of the building exteriors facing the Esplanade of State (figure 5) is of unusual interest. These exteriors have 6 large portals, 3 on each side of the esplanade. The portals are separated by large courts (figure 2). In each portal and facing the reflecting basin is a large niche containing a statue of a female figure of heroic size. These statues, 6 in all, are symbolical of the historical periods of Texas as represented by the 6 flags of Texas. Each figure is lighted by colored floodlights placed near the foot of its supporting pedestal at either side. At night the back of each niche is floodlighted from the bottom by a base light of a saturated color such as blue or green. Superimposed upon this base light at the back of the niches are many shafts of light projected from openings in the inner perimeter of the niches. Although of a hue different from the base light, the superimposed shafts of light in one niche are of one hue which changes slowly, fading from one hue into another under electronic tube and reactor control. The effect is a beautiful, slowly changing iridescent pattern, forming a background for the heroic figures (similar to figure 6).

The wall surfaces of the 4 courts between the 6 portals are floodlighted in mobile colors. There are 4 hues: amber, red, green, and blue. Saturated colors are used, one fading slowly into the next consecutively through each color of the cycle. Each of the 4 courts has been landscaped, one each representative of the 4 limits of the great state of Texas. This landscaping, consisting of palm, pine, sycamore, and oak trees, is silhouetted at night by the bright surfaces of the court walls. The walls of the 4 courts lighted in mobile colors have a total area of approximately 28,000 square feet and are lighted by 96 amber, 120 red, 240 green, and 304 blue 1,000-watt floodlight units. The total connected load of this mobile color lighting is approximately 760 kw. The mobile color lighting of the niches, totaling approximately 110 kw, is controlled by the same electronic tube and reactor unit, thus a total of approximately 870 kw is controlled from a single controller shaft although the electronic tube and reactor elements are located in 2 different control rooms, one on each side of the esplanade.

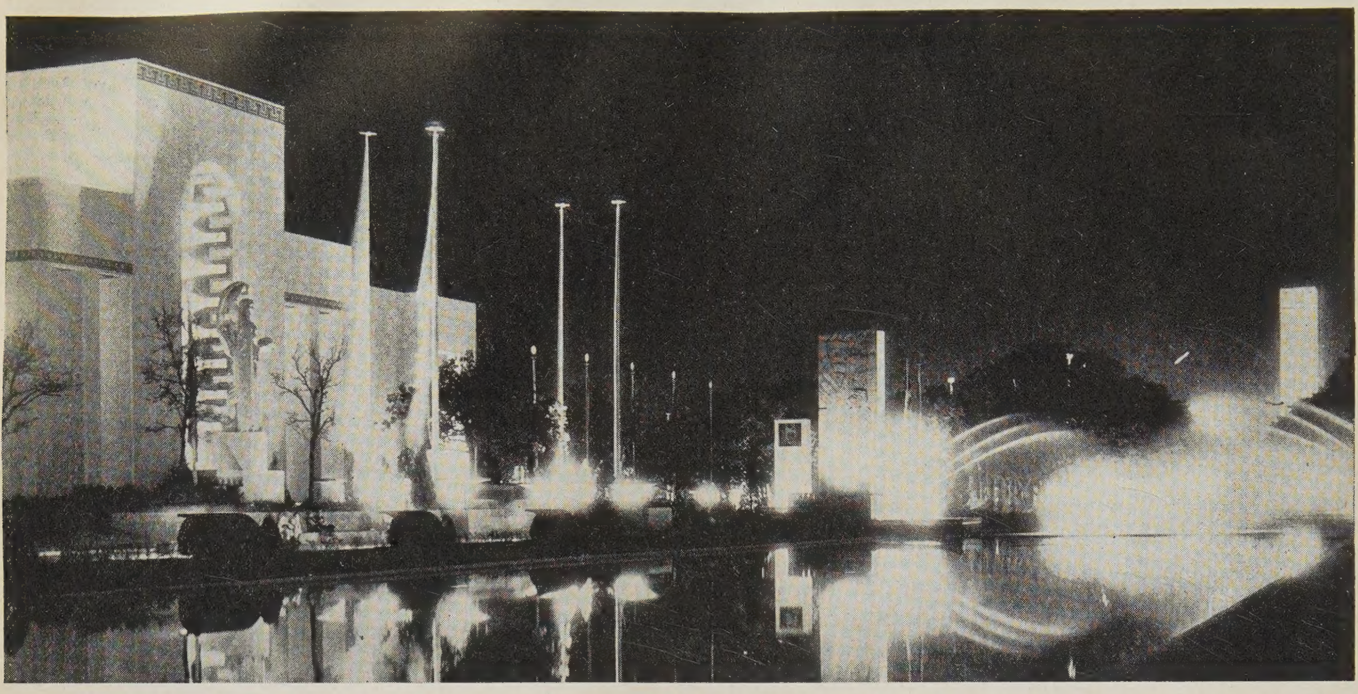


Fig. 5. The heroic figure and niche in one of the large portals facing the Esplanade of State. At the right may be seen the fountain at the entrance-plaza end of the reflecting basin. Low lighting units (see figure 8, units B and C) are aligned along the walk next to the reflecting basin

An interesting illuminated figure occupies a niche at the entrance to Garner Hall (figure 6). This niche is similar to those in the esplanade except that a reflecting basin and small illuminated water fountains are a part of the composition.

A tower 175 feet high located at the main entrance to the Federal building has been painted white and is illuminated at night by white light to an intensity of approximately 50 foot-candles. The height and

relative brightness of this tower cause it to stand out into the night and it may be seen from a distance as well as from the exposition grounds.

There are several lighting pylons built into the architecture. The glass brick pylon on the axis of Agrarian Drive built into the poultry building is approximately 50 feet high and is particularly interesting. The glass bricks are lighted from behind by red, green, and blue incandescent lamps on 12-inch centers, totaling approximately 15 kw. These lamps are controlled by a flasher to give fast moving patterns within the pylon in varying colors.

The illumination of the exteriors of private exhibit buildings like the illumination of the interiors of these buildings reflects the tastes of the individual designers yet complies with the rules of the exposition. Private building exterior illumination, except within the Midway area, differs little from the regular illumination as provided by the exposition corporation. A marked exception to this is the General Motors exhibit building. The exterior of this building has not been generally illuminated. As a substitute a moving letter sign has been provided. This sign attracts the attention of many people as they enter the exposition grounds.

Midway structures (figure 7) consist principally of fronts which usually are bright and spectacular. These fronts, because of restricted space, cannot be floodlighted easily. Lighting, therefore, has been accomplished principally by architectural lighting elements although floodlighting has been used. Exposed lighting, such as exposed inside-frosted lamps, has been used extensively in this area and it is not particularly objectionable if large areas or clusters of lamps are used together to reduce spot glare. Brightness seems to be particularly desired by showmen.

The intensities of illumination on the exterior surfaces of buildings, expressed in watts per square foot of surface lighted, are approximately as follows:

a. White light on museums and similar buildings, from 0.6 to 2 watts; white light on Federal building tower, 8 watts; white light on the Ford building's upper set-back wall, in excess of 15 watts.

b. Colored light on main exhibit buildings in static color, from 3 to 5 watts, and in mobile color, 27 watts.

c. Murals in direct white light, from 3 to 6 watts, and colored bas-reliefs in direct light, from 3 to 4 watts.

The total building exterior electrical lighting load has been estimated at approximately 3,250 kw.

Illumination of Streets and Grounds[2]

The illumination of streets and grounds at the Dallas exposition results from many elements, as follows: street-lighting units operating from series lighting circuits, lighting units for streets and grounds operating from multiple lighting circuits, lighted pylons, lighted concession stands, illuminated flags and banners, illuminated fountains, searchlights, and light reflected from building exteriors. This illumination has been co-ordinated with architecture and landscaping and so designed that it does not interfere with the illumination effects on building exteriors. The lighting units are festive and stimulating by daylight as well as at night.

The series-circuit street-lighting system is a permanent improvement. It consists of 63 ornamental standards of a specially designed modern type with 10,000-lumen single light source, 18 feet above the ground. The units have been provided with insulating transformers in the bases and are served by approximately 21,000 feet of 15,000-volt underground cable from 2 circuits so arranged that 43 units are lighted from dusk until dawn and 20 units are lighted from dusk until midnight. In addition to these there are 13 bracket-type 4,000-lumen lamp units served by overhead circuits and distributed along service roads. The series lighting system does not depend for energy upon the regular feeders to the exposition grounds, hence it serves principally as an emergency street-lighting system.

Multiple street-lighting units are served by "midnight" circuits which are energized from dusk until midnight and by "all-night" circuits which are energized from dusk until dawn. There are some 331 such units of 18 different types or designs, located along streets and walks. These have been provided and are operated by the exposition corporation. There are many other lighting units for streets and grounds that have been provided by concessionaires

Fig. 6. The illuminated niche and fountains at the entrance to Garner Hall. The method of lighting this niche is similar to that for the 6 heroic figures in the Esplanade of State

and exhibitors within their private areas. Street-lighting units are of special and unusual designs (see figure 8) and require from 500 to 3,700 watts each. Seventy-six of these units owned by the exposition corporation have been provided with a total of ap-

proximately 3,200 feet of gaseous-conductor tubing. Many of the street-lighting units have been designed for indirect lighting and are less than 5 feet high so that they are not in the direct vision of persons viewing the illumination of building exteriors. In addition to the above there are approximately 100 small ground-lighting units requiring 150 watts each. These ground lights, served by "midnight" circuits, have been distributed along walks and in gardens in subdued light areas.

Large street-lighting units, architecturally treated, have been classed as street-lighting pylons. There are approximately 30 such pylons in 9 different designs and types (see figure 9). These are all served from multiple lighting circuits and are usually provided with both midnight and all night service. Pylons are lighted by floodlights, strip lights, and gaseous-conductor tubing. Pylons require from 2,400 to 8,700 watts each. In addition to these there are 19 pylons which house the loud-speakers of the official public address system, and these pylons are floodlighted at night from shrubbery around them. At each principal entrance to the exposition grounds there is a large pylon. The pylon at the main gate is a permanent concrete structure 85 feet high. It is floodlighted by white light totaling approximately 30 kw. Three other entrance pylons require from 5 to 16 kw each.

Concession stands (see figure 10) within the exposition grounds and ticket booths at entrances are located where people congregate. Lighting coves containing 40-watt lamps on 12-inch centers have been provided around the tops of these stands and booths. These coves have been designed to serve as sign shelves for cut-out letters and to throw considerable indirect light into the surrounding area. Concession stands have well-lighted interiors and some of this light reaches the areas in front of the stands.

There are approximately 400 large flags and banners within the exposition area. Most of these are illuminated at night by floodlights concealed in shrubbery, street-light units, pylons, concession stands, and other available structures.

There are a number of illuminated fountains about the exposition grounds. The 3 principal permanent fountains are as follows: At the entrance-plaza end of the reflecting basin in the Esplanade of State are 2 pylons 35 feet high which have been ornamented with colored bas-reliefs and are illuminated at night. From each of these pylons emanate water cascades and jets which discharge into the reflecting basin. The cascades and jets are illuminated by amber light from underwater floodlights to give an appearance by night of flowing molten metal. At the Court-of-Honor end of the 700-foot-long reflecting basin is a single pylon 50 feet high. This pylon appears luminous at night when lighted by 50 kw of concealed green incandescent lamps. Cascades of water and a 75-foot stream of water issue from the base of this pylon into pools of water retained at the head of the reflecting basin by glass-brick weirs. The cascades and stream of water are illuminated by amber underwater floodlights while the glass-brick weirs at 2 elevations are back-lighted under water by green lamps.

A fountain has been provided in the center of the

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Fig. 7. Night view of the Midway. Note the bright fronts of the concession buildings

A—Unit of a modern type providing 1,400 watts of indirect lighting

B—Low unit with flag poles. This unit provides 1,700 watts of indirect lighting plus 2 1,000-watt floodlights for flags

C—Low unit which provides 800 watts of indirect lighting for sidewalk. These units are spaced quite close together

D—Large unit with light from 3 1,000-watt floodlights projected on panels to provide indirect light for street

E—Park area units with 1,600 watts to give indirect light from undersides of disks

F—Floodlight unit used for lighting museum buildings with white light

G—Large unit on approach to Court of Honor with 2 1,000-watt floodlights projecting light onto under side of curved top to give indirect light toward street, and with 40 feet of gaseous-conductor tubing on under side for ornamental purposes

H—Series-circuit-type lighting standard with 10,000-lumen lamp

I—Secondary-roadway-type unit with one 500-watt processed lamp projecting light onto underside of square plate to give indirect lighting for street, and with 10 feet of gaseous-conductor tubing used at the top

J—Typical outdoor fire-alarm box

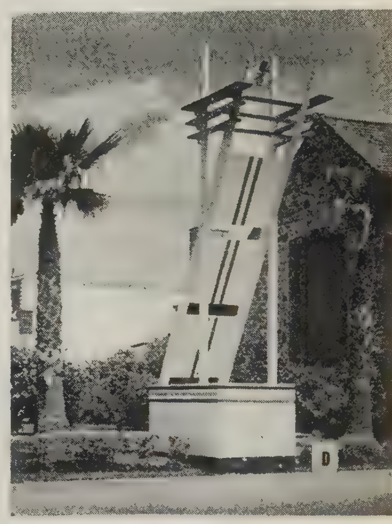


Fig. 8. Typical street-lighting units

lagoon (figure 11) in the park area. This fountain is approximately 100 feet wide, consisting of 3 sections—a center section and 2 wing sections. The center section contains a 20-millimeter central nozzle and 4 smaller nozzles. Each wing section contains 9 nozzles, all of which are aligned on the central nozzle. The central nozzle projects a stream of water vertically about 72 feet at its highest. All other nozzles project streams of water toward the central nozzle at heights varying up to 32 feet. The effect is many plumes of water in a line and inclined toward the central column of water. The fountain is illuminated at night by red, amber, green, and blue underwater floodlights made mobile by electronic tube and reactor control. The color changes and automatic water effects are controlled according to a predetermined cycle by a motor-driven controller. This fountain requires approximately 30 horsepower of pumps and has a lighting load of 50 kw. The fountain, although not large, is very popular with visitors at the exposition. People appreciate combination water and lighting effects.

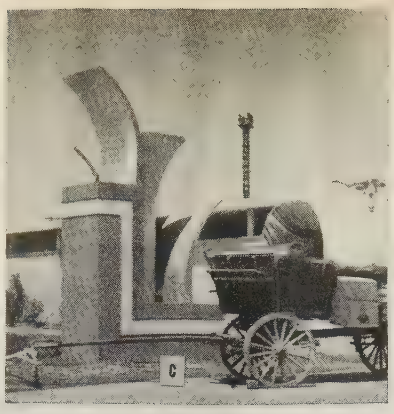
There is a bank of searchlights (figure 12) consisting

A—Large pylon combined with flag pole with 7,000 watts of lighting projected up onto fins to give indirect lighting for street, and having in addition 2 1,000-watt floodlights for lighting flags

B—These large pylons are part of the exhibit building and are lighted indirectly by gaseous-conductor tubing

C—Pylon in agrarian area with 4 1,000-watt floodlights provided to illuminate the 4 undersides of the curved projections

D—Large pylons at main entrance with 5 1,000-watt floodlights provided to illuminate the 5 faces of the pylon, with 1,000-watt floodlight to illuminate flag, and with 100 fee of ornamental gaseous-conductor tubing



E—Midway pylon provided with 2,200 watts behind decorated translucent material plus 50 feet of gaseous-conductor tubing

Fig. 9. Typical street-lighting pylons

of 24 36-inch medium-intensity arc 125-volt d-c units of approximately 60,000,000 beam candlepower each. This bank is located directly behind the State of Texas building upon the main axis of the Esplanade of State. Transparent screens in colors of medium red, medium amber, light green, light blue, and light magenta are used with these searchlights. As visitors enter the exposition grounds by the main entrance the searchlights in white light, or in varied colors, form a beautiful scintillator background for the Esplanade of State and Court of Honor. The searchlights also serve as a marker for the exposition grounds from a distance.

The Cotton Bowl, designed primarily as a football stadium, seats approximately 46,000 people. It is floodlighted at night from 6 floodlight towers (see figure 12) located 3 on each side of the bowl and spaced approximately 150 feet apart. Each of these towers supports 8 1,500-watt floodlight units which are burned at 10 per cent overvoltage, making a total lighting load of approximately 80 kw.

The total street and grounds lighting electrical load, including fountains and searchlights, has been estimated at approximately 1,500 kw.

Electrical Heat and Power Requirements

The electrical power requirements at an exposition are quite extensive and varied. The most important power requirement at the Dallas exposition is for air conditioning and ventilation. Refrigerated air conditioning has been provided within the exposition area at 37 locations with a total net floor area of approximately 310,000 square feet. This equipment has a total capacity of approximately 1,500 tons and requires approximately 1,800 horsepower to drive compressors alone. An estimate of the total gross floor area benefiting by refrigerated air conditioning is approximately 10 acres. The exposition corporation's exhibit buildings, in addition, have been provided with ventilating systems designed to produce an air change of from 4 to 6 cubic feet of air per minute per square foot of floor space. Air enters these buildings by the entrance doorways which ordinarily remain open. It circulates into exhibit spaces and through ceiling grilles into a plenum space between the ceilings and the roofs of the buildings from where it is discharged to the outside by exhaust fans. A total of approximately 200 horsepower in driving motors is required for the exposition corporation's ventilating systems alone. Private buildings probably use a total in excess of 500 horsepower for similar purposes. This latter figure includes ventilating equipment for refrigerated air conditioning.

An important item is the multitude of small portable fans. This load in some places exceeds $^1/_2$ watt per square foot of available floor area.

The power required to operate equipment in exhibits and concessions is extremely varied and a detailed discussion is not justified. A few interesting instances, however, are as follows: Sixty horsepower is required to freeze and maintain the open-air ice-skating rink at the "Black Forest" concession. Sixty horsepower is required to cool water for the aquarium. Two hundred horsepower is required to operate the racing coaster concession and the "rocket speedway" has a starting current of approximately 800 amperes at 208 volts and 60 cycles. A 400 horsepower motor is used with the air conditioning equipment in the Ford exhibit building.

Electrical heating requirements are negligible although many toasters, percolators, and similar appliances are used in some locations. Space heaters will be used to a limited extent in open concession stands during cool days.

The total heat and power electrical load, including air conditioning, ventilating, and miscellaneous power, has been estimated at approximately 3,500 kva.

"Cavalcade of Texas" and Special Events

The "Cavalcade of Texas" is a large historical pageant which summarizes the stream of Texas history by a series of fast-moving episodes. The whole production requires only $1^1/_4$ hours. It has a cast of approximately 200 persons and a setting approximately 300 feet wide by 160 feet deep. Acting is in pantomine and the speaking, music, and sound effects are produced by a special personnel in a studio, from where they are transmitted to loud-speakers suitably located. Settings are changed behind an illuminated water curtain. Ninety-two 1,000 to 1,500 watt reflector spots in 4 colors, with resistor dimming, are used to pick out playing areas. There are, in addition, a number of 1,000- and 2,000-watt lens spotlights and 8 80-ampere d-c arc spotlights. The latter are served from a small a-c to d-c substation. The stage settings are moved in and out with the episodes and carry their own lighting. The spectacle has a connected load of approximately 250 kw. The casting is controlled by extensive private telephone facilities located in dressing rooms, studio, projection room, and wings.

Special events require special electrical facilities and a flexible electrical system. The special event requiring the most extensive electrical layout was the "Hollywood Electrical Pageant" held in the Cotton Bowl. The arrangements for this pageant included a 450-kva 3-phase 4-wire transformer station, from 4,160 volts to 240/416 volts star, and a double-trolley system 18 feet high (figure 12) and approximately 1,200 feet long with switching facilities and feeders. Ten large floats, each containing from 40 to 50 kw in incandescent lamps, were lighted by energy taken from this trolley system as they were towed around the stadium just inside the playing field. As many as 8 floats, totaling approximately 360 kw, were used simultaneously. Other requirements for special events are power and light for theatrical productions and miscellaneous open-air features.

Electrical Supply and Primary Distribution

Electrical energy is supplied to the exposition grounds by the Dallas Power & Light Company. The energy is received from 2 13,000-volt feeders which arrive at the exposition grounds by independent routes from the local main generating station. A third 13,000-volt feeder also arriving by an independent route is available in case of an emergency. Electricity is purchased wholesale by the exposition at 2 metering points. Two main substations have been provided and are located at opposite sides of the grounds. Each substation contains 2 complete 3-phase transformer units or banks and transforms part of the energy passing each metering point from 13,000 to 4,000 volts. The transformer capacities of these main substations are 4,500 kva at substation *A* and 4,200 kva at substation *B*.

Primary electric distribution is by both 13,000-volt and 4,000-volt circuits and is practically all underground throughout the exposition area. The underground system consists of approximately 7,500 feet of 2-duct main conduit lines, 3,500 feet of single-duct service lateral conduit lines, 36 manholes, 6,000 feet of 3-conductor 400,000-circular mil cable, and 30,000 feet of single-conductor cable in sizes from No. 6 American wire gauge up to 250,000 circular mils. Primary distribution is by 4 wires with a 2/0 bare stranded copper wire neutral, buried under the conduit lines. The 4,000-volt underground distri-

Fig. 10. Concession stands. Note the arrangement of sign shelves provided with approximately 40 watts per lineal foot for indirect lighting of areas in the vicinity of stands

bution system has been laid out with sectionalizing facilities. An overhead system around the back sides of the exposition area consists of approximately 9,500 feet of pole line.

The primary distribution system and practically all of the transformer stations have been installed, operated and maintained by the electric service company. There are 38 "points of delivery" from the electric service company to the exposition corporation. These may be summarized as follows: 7 points ranging in capacity from 300 kva to 1,500 kva, which provide 3-phase transformation from 13,000 volts to 120/208 volts star and which have a total capacity of 3,900 kva; 28 points ranging in capacity from 30 kva to 1,200 kva, which provide 3-phase transformation from 4,000 volts to 120/208 volts star and which have a total capacity of 9,300 kva; 2 points that provide single-phase transformation from 2,400 volts to 115/230 volts and which have a total capacity of 40 kva; and 1 point consisting of a 500-kva 4,160-volt 60-cycle synchronous motor, driving a 350-kw 125-volt d-c generator to supply power to the searchlight bank. The total secondary rated capacity is 12,970 kva at 120/208 volts star, 60 cycles; 350 kw at 125 volts direct current, and 70 kva additional at 120/208 volts star, 60 cycles, that is generated by 2 gas-engine-driven generator sets within the exhibit building of the Dallas Gas Company.

Transformer banks are located in outdoor transformer yards which are made an architectural part of buildings, in regulation transformer vaults, and in fenced-in yards behind Midway buildings where such yards are inconspicuous. Transformer banks are protected on the high voltage side by fuses and protected against overload by observation of load conditions as required during peak load periods. Transformers are accessible only to employees of the electric service company, hence secondary busses constituting points of service to the exposition are carried to nearby load centers, switchrooms, or switchboards.

Wiring of Buildings

Wiring methods used in the interiors of permanent buildings other than exhibit buildings are of the customary forms consisting of a point of service, a main switchboard provided for metering, main feeders through conduit to sub-panels, and branch feeders through conduit to loads.

Wiring methods used in the interiors of the semi-permanent exhibit buildings consist of a point of service, a bus from this point of service supported around the walls of a switchroom, and safety switches in sizes from 30 amperes to 1,200 amperes, installed on the walls of these switchrooms directly below these busses. Main feeders from the safety switches have been carried in industrial-type wireways to the load centers in the buildings. Load centers have been located above the ceilings, thereby saving the electrical materials and wall space necessary to bring the load centers to within reach of the floor. Cat-walks were provided above ceilings so that load centers are reasonably accessible. The load centers constitute the "points of delivery" to private branch circuits for the sale by the exposition corporation of electricity to participants of the exposition. There are 5 classes of main circuits within the main exhibit buildings. These are known as X, N, F, R, and E circuits. The X circuits remain energized 24 hours per day. The R circuits which serve the illumination of halls and corridors are energized each day during the period that the buildings are open to the public. The N circuits are for lighting the exteriors of buildings. The F circuits serve the building ventilating system. The E circuits constitute the emergency lighting circuits and remain energized 24 hours each day. The E circuits are energized from regular a-c sources except when these sources fail, whereupon they automatically transfer to storage-battery sources. Exhibitors are ordinarily served from X circuits and their services are provided with main switches of the meter type and meters in the exhibitors' space. All interior main feeders were originally designed of a capacity sufficient to supply the requirements of the halls and corridors and approximately 4 watts per square foot for exhibit spaces, although wireways were provided large enough for 10 watts per square foot in exhibit spaces. Additional feeder capacity has been placed in the wireways as required. Branch feeders in main exhibit buildings are in conduit to fused centers or to exhibitors' main switches from whence they have been run to their respective loads by any suitable method of wiring approved in the National Electrical Code, except open wiring. Metallic raceways which enclose both the lamp receptacles and the wiring have been used extensively in cove and trough lighting where lamps must be installed economically on close spacings.

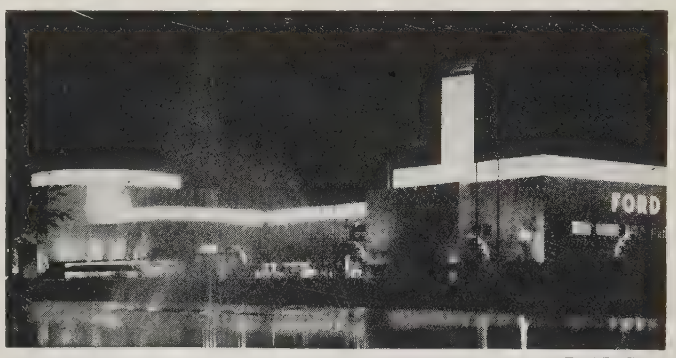


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Fig. 11. The lagoon fountain and the Ford building. The fountain is more interesting with a darker background such as may be seen in the opposite direction. The upper set-back wall of the Ford building has floodlighting in excess of 15 watts per square foot. The white shaft is the tower of the Federal building which is beyond the Ford building

The wiring methods used in private buildings were similar to methods already described, the nature of the wiring in each case depended upon the size and permanence of the building wired.

Circuits for the illumination of the exteriors of

buildings have been carried directly from switchrooms by conduit or underground cable to load centers usually located outdoors. These circuits, which are N circuits, have been provided with separate switches so that they are independent of the circuits for the interiors of the buildings. From the load centers the floodlighting circuits branch out to surface-mounted single-unit lock-type plug receptacles so located that floodlights may be connected to the outlets by all-rubber duplex cords 10 or 15 feet long

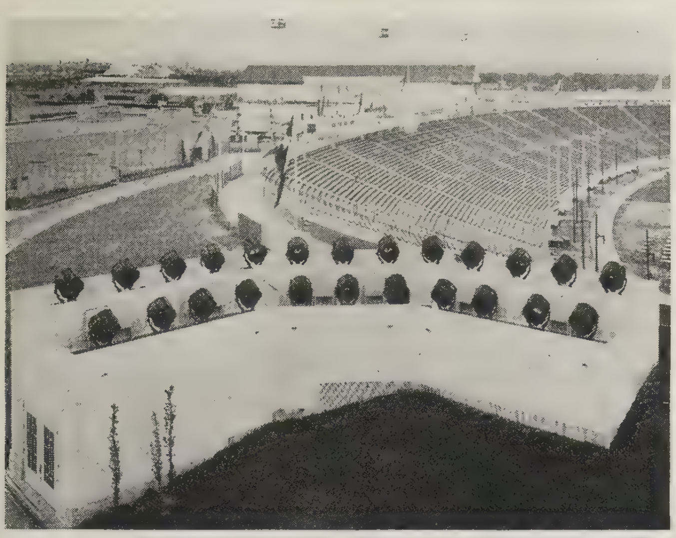

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Fig. 12. Searchlight bank and substation. Note the stadium floodlight towers. In the stadium may be seen the trolley line for the Hollywood pageant

provided with rubber lock-plugs. Floodlights for mounting on the ground have been provided with a pipe support driven into the ground.

Outdoor Secondary Distribution

Secondary electrical distribution, whether indoor or outdoor, is by the 120-volt single-phase, 208-volt 3-phase, 4-wire star system with grounded neutral.

Outdoor secondary electrical distribution is underground. Cables and wires have been laid directly into the ground except under streets and major walks. The circuits originate in switchrooms or load centers either in major buildings having transformer vaults or in switchrooms provided adjacent to transformer yards. The wiring methods in independent switchrooms are similar to those used in switchrooms in major buildings, that is, a main bus serves safety switches installed on the walls of the switchroom. The safety switches serve circuits to the outside and these circuits are in conduit to a point outdoors and underground, from where the circuits radiate to smaller buildings, to concession stands, to smaller load centers, or to street-lighting units as required.

Main underground secondary feeders are of 3-conductor nonmetallic cable approved for underground service. This cable is accompanied by a bare neutral to provide 4-wire service. Branch underground secondary feeders, if installed for a period not longer than 18 months, are of single-conductor double-braid 30-per cent-new-rubber insulated wire up to size 2/0 *AWG*. This wire was selected as an economy measure after soil tests and consultations with manufacturers' representatives. This wire ordinarily is in evening service circuits which are energized only 5 hours each day.

The wires and cables used in the outdoor underground secondary system by the exposition corporation alone vary in size from number 10 *AWG* up to 500,000 circular mils, and these wire lengths total more than 50 miles in all. In addition to these totals, all exhibitors and concessionaires provided their own feeders and secondary distribution.

Consumption and Sale of Electrical Energy

The exposition corporation purchases approximately 2,600,000 kilowatt-hours per month with daily maximum demands varying from 8,200 to 9,000 kw. The exposition corporation, through its utilities division, sells electrical energy to participants of the exposition approximately as follows: 200 unmetered services of less than 1,000 watts connected load; 250 metered services with maximum demands less than 50 kw; 17 metered services with maximum demands between 50 and 200 kw; and 5 metered services with maximum demands between 200 and 1,400 kw.

Telephone Facilities

At the Dallas exposition there are within the grounds approximately 155 telephone stations connected directly with outside telephone exchanges; 217 public or pay telephones located at suitable places about the exposition grounds, and 5 private branch exchange (*PBX*) locations which serve 100 telephone stations and which are served by 30 local and 3 toll trunks. Eight toll trunks serve the American Telephone & Telegraph Company's exhibit alone. In addition to the above the exposition corporation has a 6-position main switchboard from which radiate 284 telephone stations and 60 or more telephone extensions. The main switchboard has available 55 local and 3 toll trunks. This main switchboard has been equipped with 2 conference strips of 5 positions each and is supplemented by 2 order turrets with 8 positions which may be used for information operators. The exposition corporation has 48 telephones of the outdoor, weatherproof type, located for police purposes at suitable places about the exposition grounds. Of these police telephones, 31 are of the no-dial type, while 17 in locations where outside calls may be necessary are provided with dials. All police telephones are connected to a *PBX* board in the police division of the combination police, fire, and hospital building within the grounds. The police *PBX* has one telephone station within the fire engine house and one within the emergency hospital. The police board has available 5 tie lines to the main exposition board and 4 local trunks to outside exchanges. Emergency service of every kind can be handled through this police board. There are in addition special internal telephone facilities at the

"Cavalcade of Texas," and for the official public address system. The telephone facilities of the exposition are served by approximately 1,700 miles of wire, enclosed in cables. Practically all of the cables within the exposition area are underground. Telephone wires also serve the requirements of the telegraph companies, private fire and watchman signal systems, and entrance gate totalizers. Approximately 2,300 calls per day are made from public telephones within the grounds and approximately 18,000 calls per day are handled at the exposition corporation's switchboard.

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Fig. 13. The large cash register which totals admission to the grounds each day. Note the street-lighting units on the Forest Avenue approach to the Midway

Protective Signal Systems

There are 2 fire-alarm systems within the grounds; one operated as a part of the city of Dallas's regular fire-alarm system and the other operated by the American District Telegraph Company. The outdoor fire-alarm system consists of 23 standard fire-alarm boxes located about the grounds and mounted at regulation heights on pedestals. These boxes are connected to the central station of the Dallas fire department by approximately 3 miles of underground cable within the exposition grounds alone. These circuits have been arranged to ring simultaneously at the 2 fire-engine houses at the exposition grounds. The indoor fire-alarm system consists of approximately 36 boxes located at suitable points within the larger buildings. The operation of one of these boxes will also ring simultaneously at the 2 fire-engine houses at the exposition grounds and in addition will ring at the central supervisory station of *ADT* in Dallas from where it is immediately relayed to the central fire station of the city of Dallas.

The watchman system consists of approximately 90 intermediate stations of the watchman compulsory tour type with approximately 20 transmitter stations. These transmitters are connected to the central supervisory station of *ADT* in Dallas, and when a transmitter is not operated according to a predetermined schedule the irregularity is immediately investigated. The exposition corporation's 2 banks are provided with holdup alarms which, when operated, produce signals in the exposition police department and in the central supervisory station of *ADT* from where the signals are dispatched to the Dallas police and instructions broadcast by police radio. To accomplish all this approximately 35 pair miles of circuits have been used. Circuits are supervised by the automatic McCulloh system.

Gate Totalizers

A special electrical system has been provided to intergrate at a central point the number of admissions of persons to the exposition grounds. Admission to the grounds is through 3-arm turnstiles which are arranged to transmit one electrical impulse per revolution, that is, one impulse for each 3 persons admitted. The exposition has 4 main entrance gates and 1 service gate. The turnstile impulses at each main gate are accumulated at the respective gate. The accumulated impulses are transmitted by wire to integrating registers located within the exhibit building of the National Cash Register Company. This building has been constructed in the shape of a large cash register (figure 13), approximately 65 feet high, and has been provided with a workable register. The intergrated admissions of the current day are posted on the register at the top of the exhibit building where they may be read by visitors within the exposition grounds.

Radio and Public-Address System

There has been provided at the exposition, under the sponsorship of the Gulf Oil Corporation, an official radio and public-address system. This system consists fundamentally of a studio building, 19 sound pylons distributed throughout the exposition area, a network about the exposition grounds of program pick-up, distribution, and control circuits, and loudspeakers, microphones, and other facilities at special locations as required within the exposition area.

The studio building contains 2 radio studios, a central control room, and the offices for the radio and public-address personnel. Each studio was carefully designed acoustically and has been provided with complete facilities for producing radio broadcast programs. Each studio has its own monitoring room adjacent. Glass windows are incorporated into one side of each studio so that visitors to the exposition may witness programs in progress in either studio from the patio of the studio building. Loudspeakers have been provided so that programs are audible to visitors in the patio. The central control room is between the 2 studios and in full view of visitors. This control room has been provided with a reproducer having 2 turntables and approximately 3,000 vertically-cut World Recording transcriptions, each containing 4 3-minute selections. The central

control room is provided with announcing microphones, master amplifiers and monitors for the public-address system, radio receiver, oscillators, and other testing equipment. It contains a patch panel which serves as the cross-connecting and control point for all radio or public-address programs either for distribution within the exposition grounds or to outside radio facilities. The sound equipment in the studio building requires approximately 3,000 watts at 110 volts and 60 cycles.

The sound pylons (figure 14) located throughout the exposition area were constructed with their sound units approximately 18 feet above the ground and were designed for sound to issue from all pylons in 2 directions, except for one 4-direction pylon. Each sound pylon contains for each direction of output one high-frequency receiver equipped with small exponential horn and one cone-type low-frequency speaker, all mounted upon a baffle approximately 6 feet square. Each baffle has been provided with enclosing sides which project approximately 18 inches front and back. Each pylon has an amplifier unit designed to give high- and low-frequency output bands dividing at approximately 800 cycles per second and to give 180-degree displacement between the movements of speakers mounted in opposite directions and adjacent to each other on the same baffle. This eliminates interference between the front and back of adjacent units. Each 2-directional pylon amplifier requires about 1,000 watts at 120 volts, 60 cycles. Any amplifier may be energized or de-energized from the central control room. The careful selection of sound pylon locations, the excellent characteristics of sound units, and close supervision assures the best in sound quality about the exposition area.

Each sound pylon is served by one program circuit and one control circuit. There are approximately 70 leased telephone pairs used throughout the exposition area for public-address and radio purposes. Additional facilities can be arranged by the telephone company on short notice.

Special loud-speaker, amplifier, and microphone facilities are available in the large livestock coliseum, the Cotton Bowl, the band amphitheater, and at the "Cavalcade of Texas." In addition, 2 sound trucks with complete pick-up, amplifier, and loud-speaker facilities are available.

Private exhibitors and concessionaires, under the control of the exposition authorities, have installed and operate many private loud-speakers, public-address systems, and private record-reproducing equipments. These are quite numerous and individual consideration is not warranted.

Fig. 14. The fountain and luminous pylon at the head of the Esplanade of State. A public-address pylon, with figure attached, may be seen at either side of the fountain. The tower on the Federal building with its 50 foot-candles of white light may be seen in the background at the left. At the right note the illuminated pylon (see figure 9, unit B) and the illuminated colored bas-relief

Contributions of Expositions to Electrical Progress

It may be said that inasmuch as expositions are often planned upon the anniversaries of great events they may not contribute greatly to the advancement of any particular industry unless in the course of events of that industry, the time is particularly opportune. In the next few years great strides will be made by the electrical industry, not particularly in the development of its physical plant but rather in the expansion of the application of its known wealth of usefulness. Perhaps then the Dallas exposition with its connected load averaging in excess of $1^1/_2$ watts per square foot for the entire 175-acre exposition area, with its extensive use of air conditioning, and with its practical yet beautiful presentation of exterior lighting co-ordinated with architecture, landscaping and artistry, may point the way to an increased usage of electrical energy.

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1. Electricity at the Columbian Exposition (a book), J. P. Barrett. R. R. Donnelley & Sons Company, 1894.

2. Illumination of Texas Centennial Central Exposition, C. M. Cutler. A paper to be published in the IES *Transactions*.

Studies of Stability of Cable Insulation

In connection with recent developments of new types of underground cables for high voltages, questions have been raised concerning the stability in service of impregnated paper insulation of the ordinary type. In addition to giving new data on the only reliable test method found for predetermining this stability—accelerated aging tests—this paper gives information on the mechanism of failure, and on the effects of variations in construction and materials. Long service life was indicated by the tests for good insulation of the ordinary type.

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Considerable new information, some of it applicable to other than 66-kv cable, has been gained in recent accelerated aging tests made by the Commonwealth Edison Company on single-conductor 66-kv cable of the ordinary type. The main purposes of this and the previous series of tests[1,2] have been to develop a method to predetermine the stability of cables after changes in manufacturing methods, insulating materials, or insulation thickness, to check the products from various manufacturers, and to determine the condition of existing lines by testing removed lengths.

This paper gives mainly the results of tests performed during 1934–35 on 31 samples of 750,000-circular mil cable covering a wide range of quality. Fewer samples are considered in some parts of the paper where all samples could not be compared on the same basis. The samples were made by 7 manufacturers in the period from 1926 to 1935, inclusive, and had nominal insulation thicknesses of 40/64, 44/64, and 48/64 inch. Each sample was generally 60 feet long with 3 sheath insulators, making possible measurements of power factor on 2 portions.

The samples were placed horizontally on porcelain insulators in the laboratory and were connected in series by means of joints designed to prevent longitudinal flow of compound into or out of the cable. This aim was closely approached, but not completely achieved.

With test voltage superimposed, heating current was circulated through the conductor for 10 hours to produce a conductor temperature of 65 degrees centigrade and during the remaining 14 hours of the day the cables cooled in air. A test voltage of $2^1/_2$ times normal voltage was applied except for 17 of the heating and cooling cycles early in the program when the voltage was reduced to $2^1/_4$ times normal because of troubles in the joints. The records obtained in these and other tests indicate that, although shielded joints taped with varnished cambric are satisfactory for service conditions and for tests at 2 times normal voltage, they may become thermally unstable because of high dielectric losses at about 95 kv for joints without reservoirs or at about 115 kv for joints on oil-filled cable.

At the maximum and minimum temperatures in each cycle, power factors at test voltage and sheath temperatures at 2 points on each test section were measured. Power factors at 15 and 95 kv at room

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1. For all numbered references see list at end of paper.

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temperature were measured occasionally and the difference between them was called the ionization factor. This voltage range is slightly greater than the commonly used range of from 20 to 100 volts per mil of insulation, for example, from 13.8 to 68.8 kv for cable with 44/64-inch insulation.

Summary

The results of these studies of single-conductor 66-kv cables of the ordinary type may be summarized as follows:

1. Accelerated aging tests are the most reliable means to predetermine the stability of the insulation of high-voltage cable in service.

2. Ten days of continuous testing at $2^1/_2$ times normal voltage for 66-kv cables with daily heating from room temperature to about 65 degrees centigrade was found to eliminate all cables of poor quality. About 4 weeks was necessary to reveal the characteristics of questionable cables, while longer tests were necessary to develop local instability in otherwise good cables. Cables of excellent quality withstood without appreciable change 7 weeks of test.

3. Initial measurements of power factor and ionization factor give little information as to stability. Judgment should be based on changes in the electrical properties with aging and on the condition of the insulation after test.

4. Longitudinal uniformity of the insulation is an important requirement in service. Separate measurements of power factor on 25-foot portions of test samples give pertinent information.

5. The data obtained confirm previous findings that the stability of the impregnating compound is a primary factor in insulation deterioration. Dyeing the tapes is an aid in detecting early stages of deterioration and hence in determining its nature.

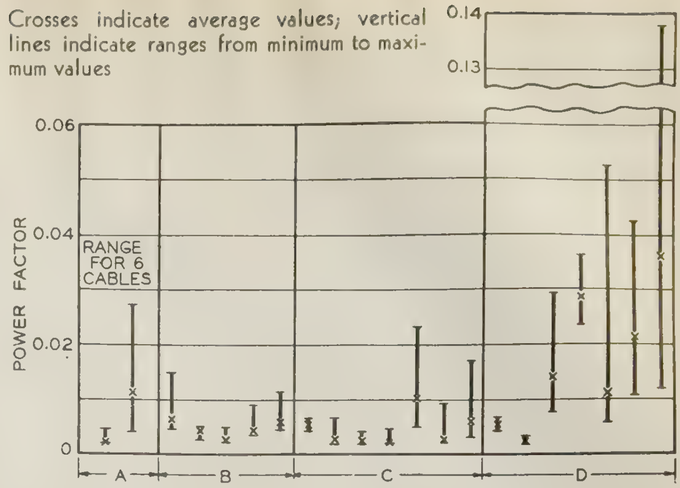


Fig. 2. Power factors of individual tapes at 60 degrees centigrade before aging tests; innermost and outermost 2 tapes omitted

6. In both test and service, deterioration appears to be started mainly by ionization. Deterioration in single-conductor 66-kv cable starts usually in the middle third of the insulation, while the final puncture may originate at the conductor or sheath.

7. The failures in test and service were of similar nature.

8. Stable cables were found to hold high vacuum for long times. This suggests that the gas content of stable cables is nearly zero and that little or no gas is developed under stress.

9. Cables of recent manufacture frequently show only fair stability.

10. The use of rosin or rosin oil in the impregnating compound appears from meager data to improve the stability of the insulation against gradual deterioration.

11. For use at 66 kv, 625 mils of good insulation of the ordinary type is sufficient for satisfactory operation.

12. The aging tests showed no definite advantage in using shielding in single-conductor cables.

13. As much as 40 per cent of the original cable insulation, if damaged in service, may be safely replaced with insulation applied by hand.

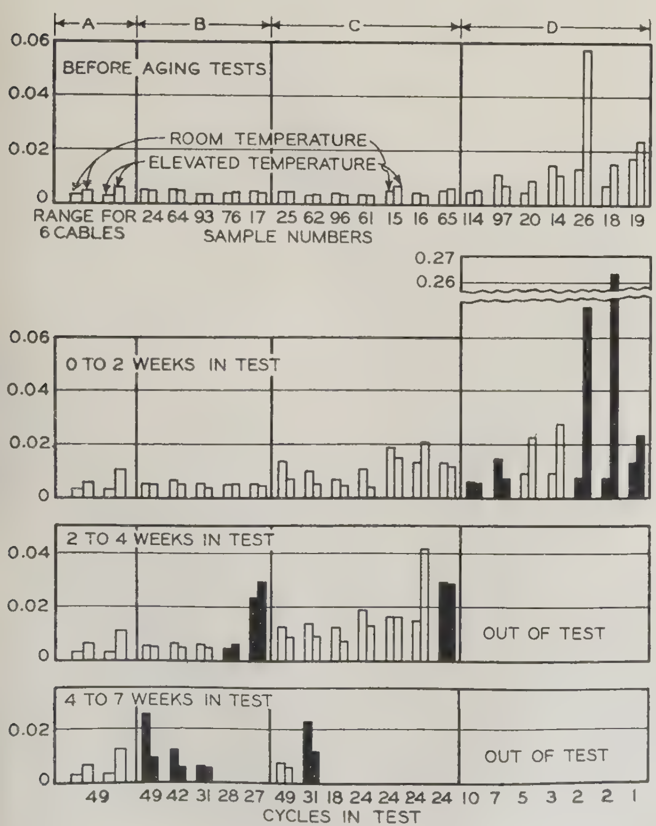


Fig. 1. Power factors at test voltage in various periods of aging tests

Shaded columns indicate cables eliminated by failure or incipient failure

Classification of Cables as to Quality

The cables have been classified in their relative order of quality according to their performance on test as follows:

Class A cables showed no signs of instability, that is, no appreciable changes in power factor, except for slight initial readjustments, during 7 weeks of aging tests and showed little, if any, sign of deterioration on dissection. Of the 6 samples in this class, 5 represented cables which are known to be satisfactory in service. The other sample represented an untried cable.

Six additional samples had the characteristics of class *A*, but they were tested for only from 13 to 31 days. They were omitted from this comparison as they might have developed instability in longer tests.

Class B cables remained stable in the tests for from 4 to 7 weeks and then developed sudden increases in power factors and failures or anticipated failures. Deterioration was found only near the failure, and the remainder of those cables that were continued in the tests after removal of the defective parts was stable. Such cable likely would give satisfactory service. Three samples represented cable which has proved satisfactory in service. The other 2 were from cable for which little or no operating experience has been obtained.

Class C cables had increasing power factor beginning during the first week, and in from 3 to 4 weeks of testing, the power factors became high enough to eliminate these cables as unsatisfactory. On

dissection, the insulation was found to be deteriorated in a large portion of the test length. Two cables had poor operating records, 1 had a good record, and the other 4 were not tried in service. The deterioration of cables in this class may not always lead to early failures, but excessive increases in power factor during service even without accompanying failure are undesirable in high-voltage cables for economic reasons.[1]

Class D cables were eliminated from the test within 10 days either because of failure or because of rapidly rising power factor. Five cables are known to have unsatisfactory service records, and the other 2 were untried.

This series of tests confirms the reliability of the accelerated aging tests in classifying the cables as to serviceability.

Duration of Aging Tests

The classification of the cables and the power factors attained in various periods of aging tests are shown graphically in figure 1. For simplicity, only the poorer of the 2 halves of each sample is represented. The power factors shown are the last ones measured in each test period. Sometimes higher values than the final ones appeared. These data give the following information on the duration of such tests:

1. A 10-day test is sufficient to eliminate poor cables (class D).
2. A 4-week test is necessary to eliminate with certainty questionable cables (class C).
3. A test longer than 4 weeks is necessary to detect local spots of slightly inferior quality.

The difference in characteristics of the 4 classes of cables suggests the important conclusion that neither changes in power factor and ionization factor nor time to failure should be used alone as the criterion of the stability of cables, but that both characteristics should be considered in judging the stability of a cable in the aging tests.

These tests indicated that unsatisfactory cables of classes C and D could be eliminated in a 4-week test either by failure or by the following limits:

	Maximum	Increase With Aging
Power factor at 95 kv	0.01	0.0075
Ionization factor	0.005	0.005

These limits might not apply strictly in all cases. For a general application of such tests, the quality of samples should be judged also by comparison with cables of known quality subjected to the same tests.

It does not appear feasible to reduce the period of test by greatly increasing the test voltage, as trials[1] at higher voltages have produced phenomena not applicable to service conditions. Likewise, it does not appear desirable to increase greatly the temperature range beyond about 40 degrees centigrade, which was used, or more than twice the usual range in service. Efforts to shorten the aging tests should include improvements in the sensitivity of the criteria of stability.

Experience at Chicago indicates that tests at about $1^3/_4$ times operating voltage are technically most attractive, but they require a duration of several months with accompanying high costs.

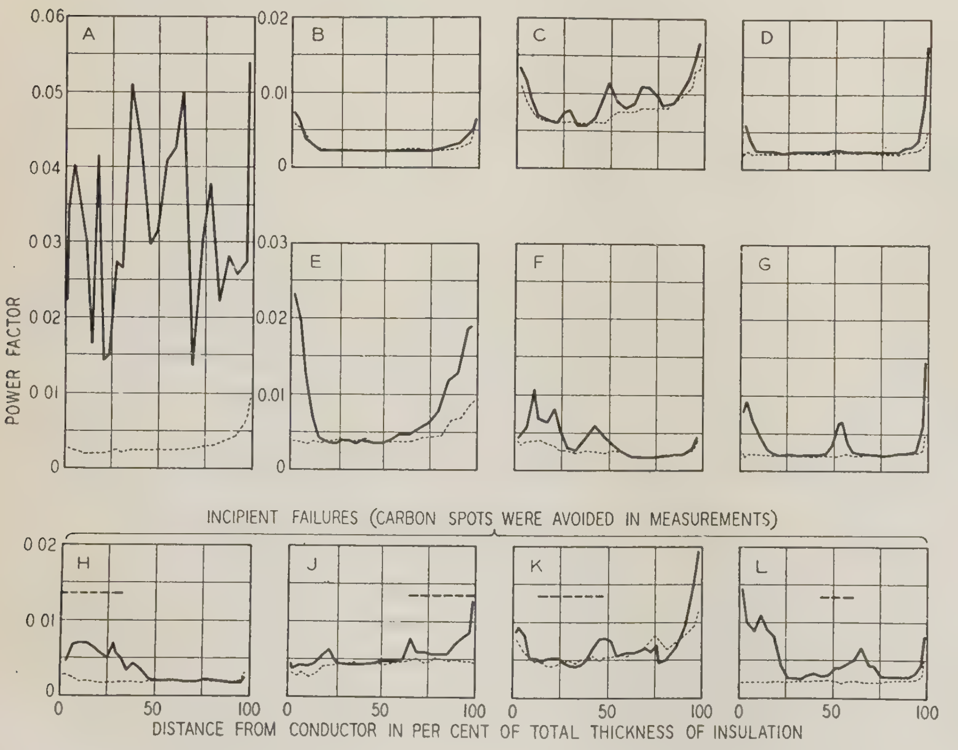


Fig. 3. Radial power factors of tape at 60 degrees centigrade before and after aging test

Dotted curves before aging; solid curves after aging; dashed lines indicate location and extent of carbon

A—Sample 16, new, 1926, unstable
B—Sample 22, new, 1930, stable
C—Sample 21, new, 1929, stable
D—Sample 60, new, 1934, stable
E—Sample 76, used, 1928, unstable
F—Sample 96, new, 1935, unstable
G—Sample 61, new, 1934, unstable
H—Sample 97, new, 1934
J—Sample 64, new, 1934
K—Sample 17, used, 1927
L—Sample 93, new, 1935

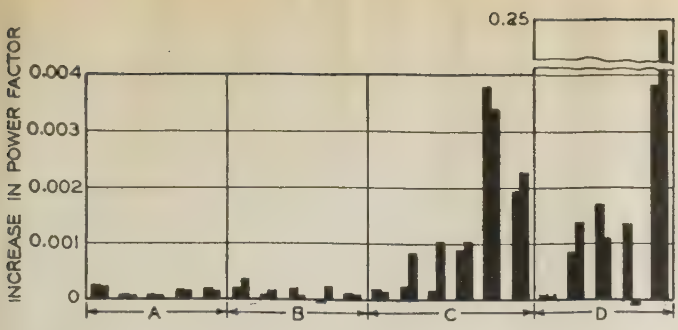


Fig. 4. Increase in power factor at test voltage at elevated temperature during aging tests for 2 halves of samples

For applying the suggested aging tests to cables that are to operate at less than 66 kv, the ratio of test voltage to operating voltage might be more than $2^1/_2$ on account of the relatively low operating stresses.

Length of Sample for Aging Tests

The test length should be at least 50 feet, but it should be subdivided electrically by means of sheath gaps, so that power factor tests may be made on sections no longer than about 25 feet. Records of cables in test and service show that deterioration is frequently nonuniform lengthwise, indicating the need for long samples. Inasmuch as the measured power factor is the average value for all insulation, a large increase in a small part might be obscured. Earlier data[1] for 2 1,000-foot samples showed increases in power factor at room temperature of 0.0009 and 0.002, respectively, before failure. The increases that were observed during tests of 25-foot samples, as shown in figure 1, were generally much larger, indicating the need for subdivision.

Initial Measurements

As shown in figure 1, the initial measurements of power factor at test voltage and various temperatures indicated the inferiority of most of the cables in class D, but showed no definite differences between the cables of the other 3 classes. The initial power factors are determined mainly by characteristics of the paper and oil in the insulation and may not be directly related to their aging properties.

Initial measurements of ionization factor indicated inferiority of only 4 of the 7 class D cables, and the ionization factors for the other 3 classes were in the low range of from −0.0001 to 0.001. Relatively small void spaces in the insulation therefore are not necessarily definite assurance of stability. In service new void spaces may be created to cause deterioration, and void spaces might be eliminated by redistribution of compound or by absorption of gas in the oil.

Tests of radial power factor[3] were made at a temperature of 60 degrees centigrade and a stress of 50 volts per mil on the tapes in an end piece from each sample before the aging tests. Such data indicate the "solid losses," or losses other than those resulting from gaseous ionization. Uniformly low values are desired because low power factors indicate low costs for insulation losses, and uniform values indicate uniformity in materials and in workmanship in manufacture.

Figure 2 shows the minimum, average, and maximum values of power factor of the individual tapes radially through the insulation. The data show that in general the more stable cables have the lower and more uniform power factors radially. There are many exceptions to this relation which indicate that other characteristics are also important in determining the performance in aging.

Increase in Solid and Ionization Losses

The data in table I show changes in losses during the aging tests. Most changes in solid losses are small and show no definite difference between stable and unstable cables. An exception to this finding, not in the table, was a petrolatum-impregnated cable made in 1926 that had an increase of 0.032 in the portion of the power factor due to solid losses during

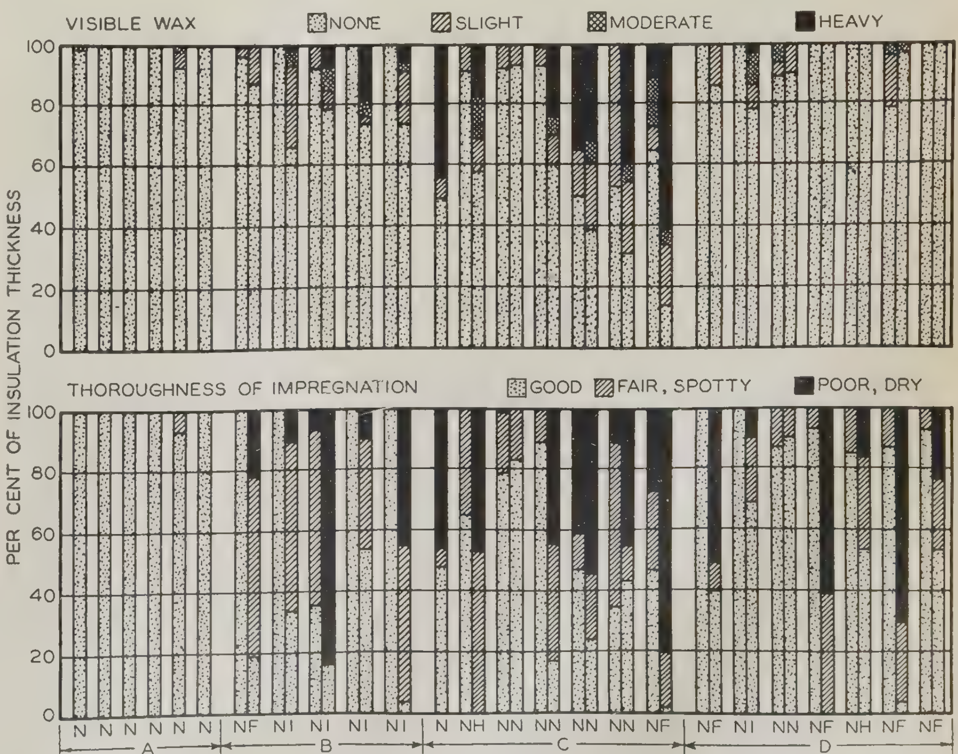


Fig. 5. Results of visual examination after tests

N—Normal I—Incipient failure H—Hot spot F—At failure

Table I—Changes in Power Factor During Aging

Class	No. of Samples	Solid Losses* at 60 Deg. C			Ionization Losses† at Room Temp.		
		Min.	Avg.	Max.	Min.	Avg.	Max.
A	6	−0.0015	0.0012	0.0040	0.0003	0.0006	0.0009
B	5	0.0009	0.0021	0.0038	0.0030	0.0153	0.0400
C	6	0.0004	0.0021	0.0065	0.0081	0.0164	0.0250
D	3	0.0011	0.0021	0.0036	No tests		

* Average of radial power factor curves.
† Change in ionization factor from initial to maximum during aging.

24 cycles of heating and cooling. Such compound appears to deteriorate rapidly under ionization.

The changes in ionization factor were in general large in cables of classes *B* and *C*. Local deterioration caused considerable ionization in class *B* cables shortly before failure. For class *C* cables the increase was gradual over a few weeks. No records are available on the increase in ionization factor during the short life of class *D* cables, but there are indications for several of these cables that ionization was a major factor in the deterioration process.

Although the changes in the average values of the curves of radial power factor were usually small, the changes in some regions of the insulation were greater. The pronounced increases occurred mostly near the conductor and sheath, but in some cases elsewhere also.

Figure 3 shows various typical curves of power factor before and after aging tests. In general, stable and unstable cables show the same types of changes in the curves of radial power factor. For cables which did not contain carbonized paths, the power factors of the complete cables agreed closely with the average values for the tapes.

Samples 60 and 61 were made by the same manufacturer, and were insulated and treated together in one length but sheathed separately with different kinds of lead. Their curves of initial radial power factor were identical. Sample 61 became unstable after 10 cycles of test and was removed in anticipation of failure after 24 cycles, while sample 60 remained stable throughout the 49 cycles of test.

In 5 cases measurements of radial power factor were made on a few inches of cable involved in

Fig. 6. Tapes showing various types of waxing and tree designs

incipient failures where a carbonized path had formed through a part of the insulation. In the tests the spots on the tapes containing carbonized areas were avoided. The results of 4 of these tests are shown at the bottom in figure 3. The increase in solid losses, avoiding paths of breakdown, was rather small, ranging from 0.0009 to 0.0025 power factor, at the points of incipient failures. In 2 cases the power factors of one-foot sections of the complete cable containing incipient failures were found to be 0.146 and 0.247, or, respectively, 26 and 36 times the average value of the power factors of the uncarbonized portion of the tapes measured at the same stress. Apparently the high values for these cables containing incipient failures were caused by the carbonized paths in the insulation and by ionization.

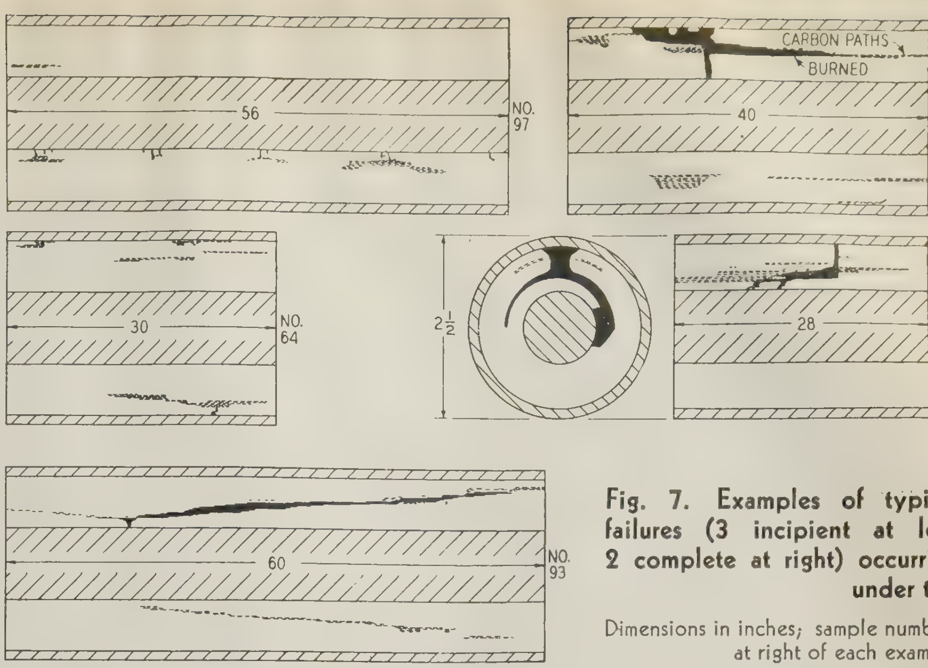


Fig. 7. Examples of typical failures (3 incipient at left, 2 complete at right) occurring under test

Dimensions in inches; sample numbers at right of each example

Longitudinal Uniformity

The differences in initial power factor at elevated temperature between halves of samples ranged from 0 to 0.0009 for cables of classes *A*, *B*, and *C*, and from 0.0005 to 0.0391 with an average of 0.0082 for cables of class *D*. As shown in figure 4, the changes in power factor during aging were irregular between halves of cables of classes *C* and *D*. They were small for class *A* cables, and for locally unstable cables of class *B* if the increase in the last cycle is excluded.

In 2 samples of class *B* cables, measurements of power factor of one foot of the complete cable at hot spots and of from 3 to 12 feet of the same cable elsewhere gave the following indications of localized deterioration, as shown by the power factors at room temperature:

Sample	Center of Hot Spot		Cable Adjacent to Hot Spot	
	15 Kv	40 Kv	15 Kv	40 Kv
17	0.192	0.247	0.0041	0.0043
64	0.139	0.146	0.0048	0.0056

Extent of Deterioration

Figure 5 summarizes the results of the visual examinations, after the aging tests for 25 test lengths. Each column or double column gives the results for one length. The condition of the best and worst portion of a length is shown in the double columns.

Class *A* cables showed little or no signs of deterioration after 7 weeks of aging. Class *B* cables showed considerable deterioration at the local points of instability and little or no deterioration elsewhere. Class *C* cables, which showed gradual deterioration under test, usually had considerable wax and poor impregnation throughout. Class *D* cables generally had poor impregnation, but little or no wax, probably because of the short time that this class was under test.

In several cases of partial failures a new method described by D. M. Robinson[4] was used to make wax visible that could not be observed by ordinary examination. In this method the oil is removed from the tapes by an organic solvent such as benzol or carbon tetrachloride, which dissolves the oil but not the wax. The tapes are immersed in dye, and the portions covered with wax remain undyed. Several dyes were tried, of which malachite green was found to be most suitable for photographic purposes. Figure 6 shows various typical forms of wax and various types of tree designs and pinholes from the path of partial failures. Wax formed on the surface of the innermost tape in the space between conductor strands is shown in *A*. Waxing in the gap between turns of tapes is shown in *A*, *B*, and *C*. Scattered wax between the surfaces of tapes is shown in *D* and *E*, while *F* and *M* show "bush waxing" as it appears near carbon spots and tree designs.

Mechanism of Failures

The nature of failures referred to briefly elsewhere in the paper is covered in detail in this section. Seven complete test failures occurred. Also, it was possible in 6 cases by closely observing power factors and sheath temperatures to remove cables shortly before breakdown.

The 3 failures which occurred during the first 3 cycles of aging tests were straight, radial punctures. All other cases of partial or complete failure progressed diagonally through the insulation with the involvement of a considerable length of cable, in one case over 5 feet, and all had extensive branch-

ing in the form of tree designs. The path of the incipient failures consisted partly of burns and pinholes through the tapes and partly of tree designs along the surface of the tapes connecting at the tape edges. All cases appeared to be in agreement with Robinson's theory that puncture in single-conductor

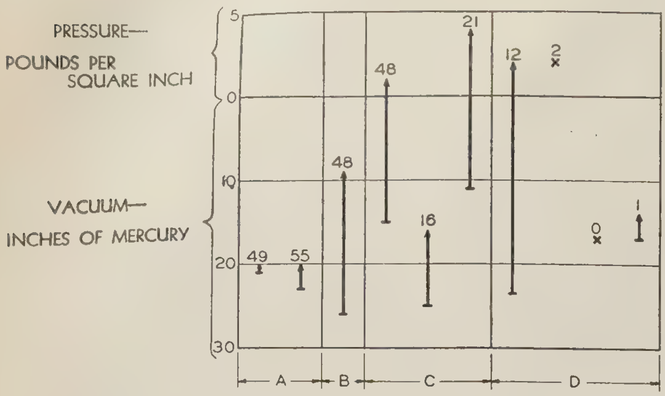


Fig. 8. Minimum pressures in 10 cable samples at start and end of aging tests

Figures indicate number of test cycles; vertical lines show changes from values after first cycles to end of test in direction of arrows

cables starts either at the conductor or at the sheath and progresses radially at first and then diagonally inward as tangential stresses develop.

Figure 7 shows 3 typical incipient failures. Sample 93 shows diagonal paths starting at the conductor. Sample 97 developed several incipient paths over a length of 5 feet which show the phases of breakdown from the initial pinholes through the layers adjacent to the conductor to the development of diagonal paths. Sample 64 shows an incipient failure starting at the sheath.

Figure 7 shows also 2 complete failures. In sample 24, the tracking started at the sheath; in sample 114 at the conductor as is usual. Probably after the insulation was sufficiently weakened by the diagonal tracking, the failure was completed by a radial puncture. The cross-sectional view of the failure in cable 114 shows that considerable spiraling of the path occurred. This phenomenon was typical for many cases of failure.

The failures obtained in these tests appear to be of the same nature as those observed in service. The 9 failures in service caused by weaknesses of the insulation of the 66-kv cables made since 1926 were in all except one case of the tracking type with formation of branching tree designs. It is questionable that all of these service failures had started at the conductor, because in most cases the branching had started 50 to 100 tapes from the conductor. In no case were tree designs found which were not connected to the main puncture. In the one service failure that was not of the tracking type, the failure was a straight radial puncture possibly similar to the first 3 failures in the tests.

Isolated carbonization was frequently found, however, in 3-conductor belted* 12-kv cables at the apexes of the conductor insulation near the cable center. These cases show that direct connection of the ionized void with conductor or sheath is not necessary to provide sufficient energy for the formation of carbon deposits.

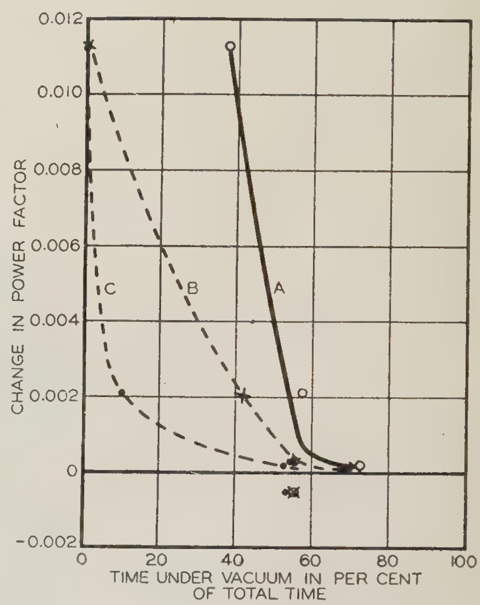
Service failures in 66-kv cables made in 1926 resulting from causes inherent in the insulation appeared to be usually of the thermal type resulting from deterioration of the compound in relatively large areas. In service, the increase in solid losses appears to be frequently more important than in test, at least for cables made prior to 1929. In both service and test, the primary cause of failure appears to be bombardment of the compound by ionization

Fig. 9. Relation between duration of vacuum and changes in power factor at room temperature during continuous 10-day test

A—Vacuum of from 0 to 10 inches of mercury

B—Vacuum of more than 10 inches of mercury

C—Vacuum of more than 20 inches of mercury



in gaseous spaces. The development of wax with accompanying liberation of gas has been found to occur mainly in the middle third of the insulation. Presumably this gas is ionized, thus short-circuiting some of the insulation in the middle third and increasing the stress in the inner and outer thirds which causes the punctures to start at conductor or sheath. It has, however, not been proved definitely in these investigations that the puncture cannot start in the ionized middle third and progress to the conductor and sheath.

Internal Pressures

Ten of the samples were equipped with pressure gauges connected through small holes at the sheath. The gauge was usually 20 feet from the center of a joint. The short connection between the cable and the gauge was evacuated and filled with oil. An attempt has been made to correlate the pressure data with the stability of the cables. Because of the many other variables involved, the relations indicated are merely trends.

Stable cables seem to develop and retain lower absolute pressures during aging than unstable cables.

* A belted cable has a wrapping of insulation over the insulated conductors after they have been twisted together.

Figure 8 shows that unstable cables had in most cases higher minimum pressures after the first cycle and in all cases considerably higher final minimum pressures than stable cables. While unstable cables gradually lost their vacuum and had accompanying increases in power factor during aging, stable cables retained the vacuum with little change. These conclusions are confirmed by pressure records obtained in aging tests made in 1928 on 66-kv cables manufactured in 1926; all samples which failed and samples which developed ionization factors above 0.01 lost their vacuum completely during aging.

Cables of classes *C* and *D* were under vacuum for from 0 to 22 per cent of the cycle at the end of the tests, while cables of classes *A* and *B* remained under vacuum for from 56 to 88 per cent of the cycle and did not decrease in duration of vacuum during aging. Figure 9 indicates a relation between the total duration of vacuum during a continuous test period and the accompanying changes in power factor.

Similarly the product of the measured vacuum and the time it was maintained expressed in inch-hours was related to the stability as is shown in figure 10. Stability increases and changes of power factor decrease with increasing numbers of inch-hours.

These findings suggest that stable cables do not contain much gas and do not evolve much gas under stress. Occurrence of vacuum in cables that are

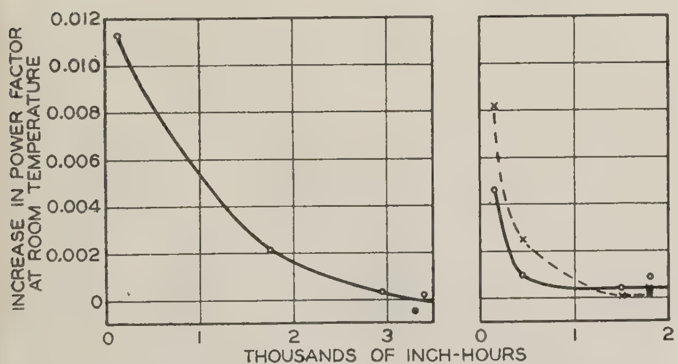


Fig. 10. Relation between stability and product of vacuum in inches and time maintained in hours

Left—Continuous 10-day test; right—continuous 5-day test
Solid curves power factors; dashed curve ionization factor

well impregnated is not so detrimental to the stability of insulation as is gas in cables that are poorly impregnated.

Maximum pressures at elevated temperature were generally found to decrease during test periods and to recover during rest periods. In several of the unstable cables the pressure range decreased to a few pounds during aging while the decrease was usually less for stable cables. It was found for cables in service that the maximum pressures not only were dependent upon the load but also were proportional to the rate of increase in load. The charges in sheath diameter found by tape measurements around the circumference were small, only a few exceeding the measuring accuracy of about ±5 mils. These changes ranged from −10 to 15 mils with an average of 2.4 mils. More accurate data of sheath expansion were obtained for one sample by means of 6 micrometer gauges of the dial type equally spaced circumferentially (figure 11).

Performance on Test of Cables Made in Various Years

Figure 12 shows the records for 28 cables separated according to the year of manufacture and subdivided into the 4 classes of stability. One of the 2 stable cables made in 1934 and the 2 stable cables made in 1935 were tested for only 4 weeks, instead of 7 weeks as were the other stable cables. The reason for the poor record of some cables of recent manufacture is not obvious, but it is to be noted that some of them were experimental lengths. Continuous close control of materials and manufacturing processes is apparently necessary.

One of the 7 cables which had been in service, for 30 months in this case, showed an excellent record in the test. Two cables, after 19 and 32 months in service, developed localized instability in the test and are therefore in class *B*. The other 4 cables after service of from 13 to 62 months were in class *D*.

Comparison of Rosin and Mineral-Oil Cables

Of 8 cables in these tests containing only mineral oil, 3 were in class *A* or *B* and 5 in class *C* or *D*. Of 6 cables containing some rosin, 4 were in class *A* or *B* and 2 in class *C* or *D*. One of the latter 2 cables tended to stabilize after about 4 weeks on test and did not fail during the 7 weeks on test. In general, insulation made recently containing some rosin or rosin oil was more stable in these tests than mineral oil insulation; but other factors may have affected the results more than did rosin.

One manufacturer furnished 2 lengths of cable which were made at the same time and were pre-

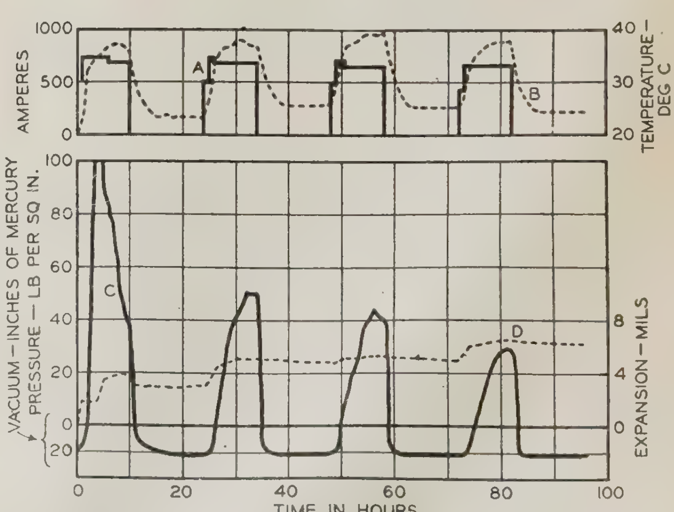


Fig. 11. Internal pressure and sheath expansion for new cable sample number 114

A—Current
B—Sheath temperature
C—Internal pressure
D—Increase in sheath diameter

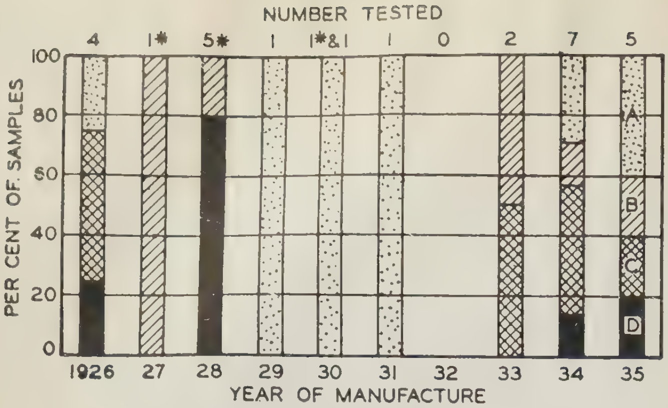


Fig. 12. Qualities of cables made in various years

* Had been in service; others were new cable

sumably alike except that one contained only mineral oil while the other contained some rosin. The latter was stable for 31 test cycles, while the cable containing only mineral oil became unstable in 18 cycles.

Although the solid losses were initially slightly lower for the mineral oil cables than for those containing some rosin, there was no noticeable difference in the change in solid losses with aging. The mineral oil cables usually had higher increases in ionization losses.

Cable With Reduced Insulation

Two cables of one make were tested which were identical except that one had the present standard insulation thickness of 44/64 inch and the other had only 40/64 inch. As shown in figure 13, they were practically identical in performance in 31 cycles of test. Also when dissected and examined after tests, the 2 samples appeared very similar. Both showed good impregnation throughout the insulation. The former showed slight wax in 38 per cent of the thickness of insulation, while the latter had slight wax in only 19 per cent of the thickness of insulation.

These and other data suggest that a reduction in insulation thickness is feasible for good insulation without appreciably affecting the serviceability.

Effect of Shielding Tape

The test results for 9 shielded* and 16 unshielded cables were analyzed in an attempt to determine the value of shielding in single-conductor cables. Four of the 9 samples of shielded cable were in classes *A* and *B*, and 7 of the 16 unshielded cables were in these better quality classifications.

In 2 cases incipient failures started at the sheath of unshielded cables, and one completed breakdown appeared to have started at the sheath in an unshielded cable. Whether or not shielding tape could have prevented this action from starting is not known, but carbon formed by deterioration of compound was found in the gaps between edges of the outer tapes in 2 other cables, one shielded and one unshielded. In other words, prevention of deterioration adjacent to the sheath is not assured by the use of shielding.

In cables deteriorated from service the deterioration is almost invariably found to be heaviest in the middle third of the insulation. This evidence indicates that after the sheath is pushed out by radial expansion of the insulating compound, the greatest void space developed upon contraction occurs within the insulation by failure of the compound to return inward.

There is no proof then in this information that shielding tape is beneficial in single-conductor cable.

* A shielded cable has a metallic tape wound over the insulation of the conductor.

Test Performance of Sheath Repairs

When an opening in the sheath of a cable in service is discovered without failure having occurred, a repair is attempted, either in the manhole or in the shop. The sheath is removed for at least 3 inches or as much as is necessary to eliminate the undesirable sheath, and the cable insulation is removed until all traces of moisture are eliminated. Tape is then applied by hand to build up the diameter to that of the original cable and a lead sheet is wrapped tightly over the gap in the sheath.

Eight sheath repairs of this kind were included in the aging tests in order to obtain information on the amount of cable insulation that could be safely replaced. Four of these repairs were made on a cable containing mineral oil and 4 on a cable containing rosin and mineral oil. Either 20 or 50 tapes, that is, up to 40 per cent of the insulation, were replaced with paper tapes or varnished cambric tapes applied by hand. No repair showed any signs of instability in more than 7 weeks of testing.

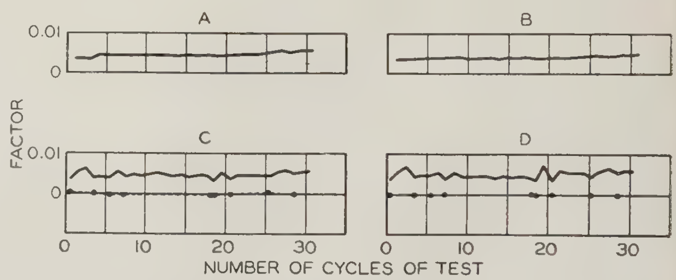


Fig. 13. Comparison of similar cables having different thicknesses of insulation

Solid curves are power factors; dots are ionization factors
A—Elevated temperature, insulation thickness 40/64 inch
B—Elevated temperature, insulation thickness 44/64 inch
C—Room temperature, insulation thickness 40/64 inch
D—Room temperature, insulation thickness 44/64 inch

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Automatic Boosters on Distribution Circuits

Development of automatic voltage regulating equipment for installation on 4 kv distribution circuits at points remote from the substation has made possible a reduction in the cost of distribution by loading circuits to their economic carrying capacities unhampered by the limitation of voltage regulation. Investigation indicates 2 rules governing the application of booster regulators, and comparisons on the basis of cost per unit of voltage improvement shows which of the several devices available should be selected to secure the lowest cost. Tests have demonstrated the practicability of this form of regulation, and its field of application is indicated by economic comparisons with other methods of maintaining voltage within the required limits.

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DEVELOPMENT of the automatic booster regulator has given to central station engineers a new device to solve the old problem of maintaining voltage on distribution circuits. The induction regulator, until recently the only device available for this purpose, is generally too cumbersome and expensive to be used commonly except in substations, and much care and expense are necessary in order to build distribution circuits so that regulators so situated can maintain the voltage. Especially is this true of long circuits feeding areas of low load density on which voltage drop establishes load limitations far below both the economic loading for the conductor size and the current carrying capacity. On many rural circuits the cost has absolutely precluded maintaining good standards of voltage. Now, however, several automatic regulating devices are available which are light enough and small enough to be mounted on a pole in a manner similar to the mounting of the well known distribution transformer. These devices afford means not only to correct poor voltage conditions, but also to increase the permissible loading of circuits now limited by voltage drop without a large expenditure for rebuilding with larger conductors. Even though such circuits ultimately are rebuilt, this procedure defers material increase in investment, sometimes for several years, and thus reduces the average cost of distribution. Where the load growth does not materialize, the boosters can be moved at small cost and the expense of rebuilding will have been avoided. The purpose of this paper is to discuss the application of automatic boosters to 4 kv circuits and to indicate the conditions for which they provide the economic solution.

Developed from a paper "Improving Voltage Regulation on Distribution Feeders" presented at a meeting of the A.I.E.E. Pittsburgh (Pa.) Section, February 12, 1935, which paper subsequently was awarded the prize for best paper by the A.I.E.E. Middle Eastern District (2); recommended for publication by the A.I.E.E. committee on power transmission and distribution. Manuscript submitted March 25, 1935; released for publication June 10, 1936.

The problem is studied as it applies to the distribution system of the Duquesne Light Company, which has few strictly rural circuits but many long suburban feeders. Practically all of these are 3-phase 4-wire 4-kv circuits with feeder regulators at the substations. The Pennsylvania Public Service Commission limits deviation from nominal voltage to ±5 per cent for lighting service, and consequently the voltage boosters are required to maintain the voltage within these limits. The secondary system design used in suburban areas has transformer and secondary drops up to 5 per cent at peak load, which leaves only 5 per cent for variation in primary voltage and part of that is sacrificed by unavoidable tolerance in voltage at the substation. The analysis by which the proper booster is selected for the application is presented herein in such a form, however, that a booster could be selected quite easily for other limits of primary voltage, and one example of this is given in the discussion of boosters for a strictly rural circuit. No mention is made of bus-regulated feeders, but it seems probable that a similar study of the application of boosters on such a system would show results even more favorable toward boosters.

With primary voltage variation limited to a 5 per cent range, the various automatic boosters listed by the manufacturers are not particularly effective because of the very limited portion of their range that can be utilized. Smaller steps are required, and a 2 step booster with 1.33 per cent steps has been found most desirable. Rural circuits present a somewhat different problem in that small individual transformers commonly are used. Less voltage regulation occurs in the transformers and secondaries, and the primary voltage variation may be increased to 7.0 per cent or more while still maintaining consumers' voltages within ±5 per cent limits. Under these conditions the boosters offered by the manufacturers are more suitable.

Economic analyses indicate the following policies in regard to the application of automatic boosters on 4 kv circuits:

1. Where the existing circuit is single phase and satisfactory regulation can be secured by adding a second phase or converting part of the circuit to 3 phase, it is usually advisable to install the additional wire, especially as this permits 3 phase load to be served. Long stretches of single phase circuit, such as 5 miles or more, may be corrected more economically, however, with boosters.

2. Where satisfactory regulation can be attained only by extensive installation of 1/0 or 4/0 conductors, then the use of boosters is often justified, particularly for circuits more than 3 or 4 miles long.

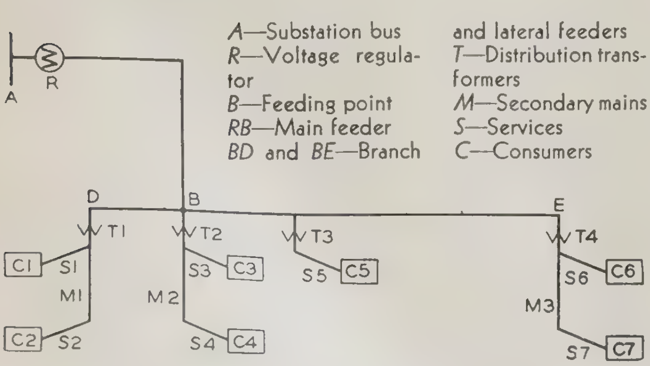
It must not be assumed that boosters can be used indiscriminately to reduce the cost of distribution circuits. Each circuit should be analyzed to make certain that the automatic booster is the proper solution. Special care must be exercised to avoid installing these devices in locations where voltage fluctuations would cause too frequent operation. The most advantageous application seems to be as an alternative to heavy conductors to maintain the voltage on long feeders, where the automatic voltage booster offers attractive economies and much needed flexibility.

Voltage Regulation on Distribution Circuits

To maintain voltage within limits of ±5 per cent is usually not at all difficult on short feeders in areas of heavy load density. The real difficulties are found in the areas of medium and light load density where the circuits must extend for miles in order to pick up a satisfactory amount of load. On such circuits it is a common practice to install a set of 3 single phase induction regulators at the substation. By means of line-drop compensators these regulators are made to vary the voltage from a value slightly above nominal voltage at very light load to a much higher voltage at full load so as to compensate for the voltage drop in the feeder between the substation and the consumers. Since these consumers are scattered over an extensive area, it is not possible to supply exactly nominal voltage to each one. It is necessary to take advantage of the ±5 per cent deviation allowed to give higher than nominal voltage to the first consumers on the circuit in order that those near the ends may have voltage not more than 5 per cent below the nominal value during the heavy load period.

The essential parts of a typical circuit are shown in figure 1. The main feeder starts from the substation bus, has its voltage controlled by a regulator, and runs without branches or transformers to the feeding point. From this point branch feeders and laterals radiate to distribution transformers which feed through secondary mains and services to the consumers. By means of line-drop compensators and voltage relays, the voltage can be regulated to compensate for the drop in the main feeder and to maintain any desired level of voltage at the feeding point. The highest voltage is found at some consumer (such as $C3$, figure 1) near the feeding point. This voltage must not exceed the nominal value by more than 5 per cent. Inasmuch as the transformer $T2$ might be lightly loaded during the circuit peak load period and have almost no voltage drop, the upper limit of voltage at B is 105 per cent. The lowest voltage is found at the last consumer on the circuit ($C7$) during the circuit peak load period when the primary branch and lateral circuit BE, the distribution transformer $T4$, the secondary main $M3$, and the service $S7$ are all carrying maximum load. This voltage at $C7$ must not fall below 95 per cent. Modern secondary system design allows 2.5 per cent voltage drop for transformers, 2.0 per cent for mains, and 0.5 per cent for services, or a total of 5.0 per cent. Consequently the primary voltage at the last transformer $T4$ must not fall below 100 per cent. In this manner the limits of voltage on the primary between the feeding point and the last transformer are established as 105 per cent and 100 per cent, or a primary voltage variation of 5 per cent. The drop in the main feeder is compensated by the regulator and does not enter as part of the primary voltage variation.

The induction regulator is not a precision instrument, however, and experience indicates that a tolerance of at least ±1 per cent must be allowed in

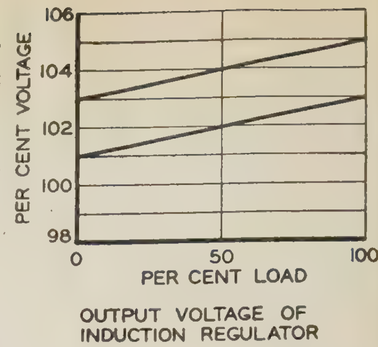


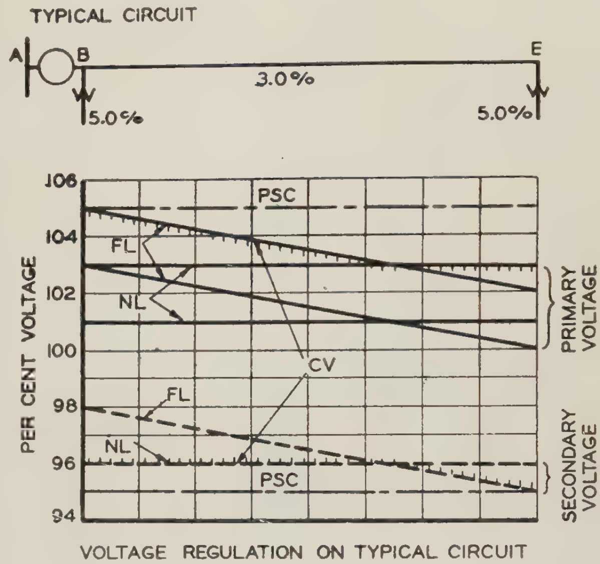
A—Substation bus
R—Voltage regulator
B—Feeding point
RB—Main feeder
BD and *BE*—Branch and lateral feeders
T—Distribution transformers
M—Secondary mains
S—Services
C—Consumers

Fig. 1. Schematic diagram of typical distribution circuit

Fig. 2. Voltage regulation of distribution feeder by induction regulator at substation

O—Induction regulator with relay set at 102.0 ± 1.0 per cent; overcompensation 2.0 per cent
FL—Full load
NL—No load
CV—Limits of consumers' voltage
PSC—Voltage limits prescribed by Public Service Commission





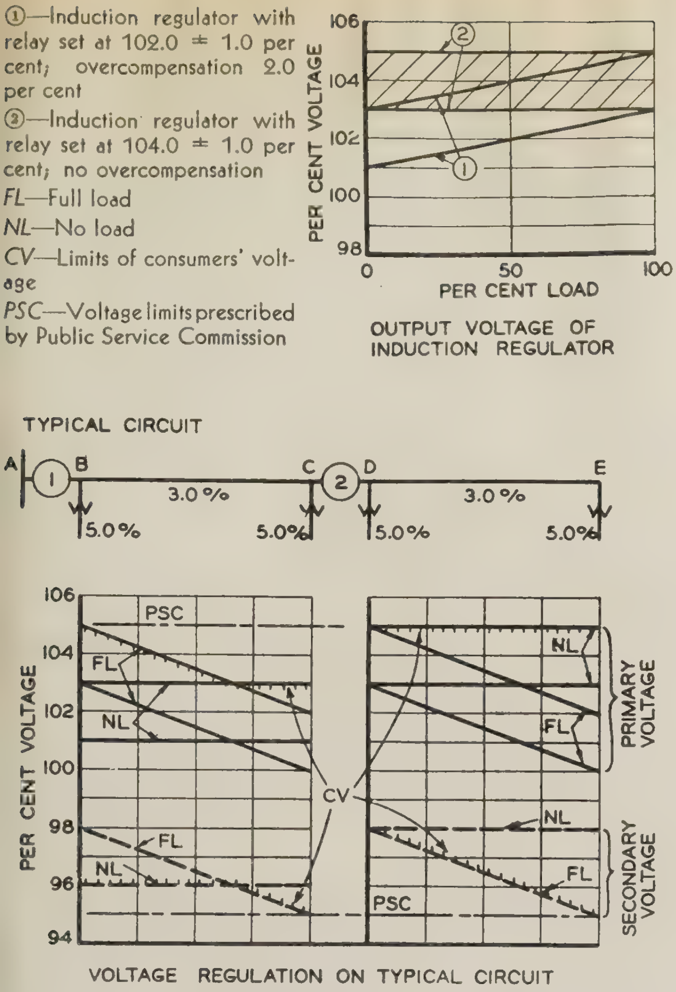


Fig. 3. Voltage regulation of long distribution feeder by induction regulator at substation and induction regulator on pole

the voltage relay setting to avoid too frequent operation. This means that compensation must be set to give not over 104 per cent voltage at the feeding point in order that the +1 per cent tolerance will not cause the voltage to exceed the 105 per cent upper limit. But the tolerance is just as liable to be −1 per cent, thereby giving a voltage at the feeding point of 103 per cent and leaving only 3 per cent for voltage drop in the primary circuit. In other words, the voltage band within which the regulator operates must be considered as part of the variation in primary voltage and must be kept to a minimum in order to allow for a reasonable amount of drop in the primary circuit.

To meet these conditions it has been recommended that the induction regulator voltage relays be balanced at 102.0 per cent voltage with the voltage raising contact 1.0 per cent below and the voltage lowering contact 1.0 per cent above. The line-drop compensators should be set to overcompensate for the main feeder by 2.0 per cent so that the voltage at the feeding point varies from 102.0 ± 1.0 per cent at no load to 104.0 ± 1.0 per cent at maximum load. The output voltage band for this setting is plotted against per cent load in the upper diagram of figure 2. Figure 2, center, shows a typical circuit with the induction regulator feeding directly at the feeding point, with primary drop of 3.0 per cent, and with typical secondary systems having 5 per cent drops distributed along the primary. The lower diagram of figure 2 shows the full load and no load primary voltage along this circuit to be within the limits 105.0 per cent and 100.0 per cent. The limits of consumers' voltage also are shown in the diagram; these satisfy the Public Service Commission's ±5 per cent tolerance and require no further consideration.

The constants of figure 2 may be seen to be the maximum that can be regulated within ±5 per cent tolerance. The only exception to this statement is found where the loading conditions are such that the highest consumers' voltages are appreciably lower than the feeding point voltage and more overcompensation can be used without exceeding the 105 per cent upper limit. Recent tests on a number of distribution circuits have indicated differences as small as practically 0.0 per cent and as great as 2.6 per cent with an average of 1.1 per cent. Taking 1.5 per cent as the greatest difference that can be considered safe, it is found that the normal voltage at the feeding point can be permitted to rise to 105.5 ± 1.0 per cent and the maximum permissible voltage drop in the primary branch and lateral circuits can be

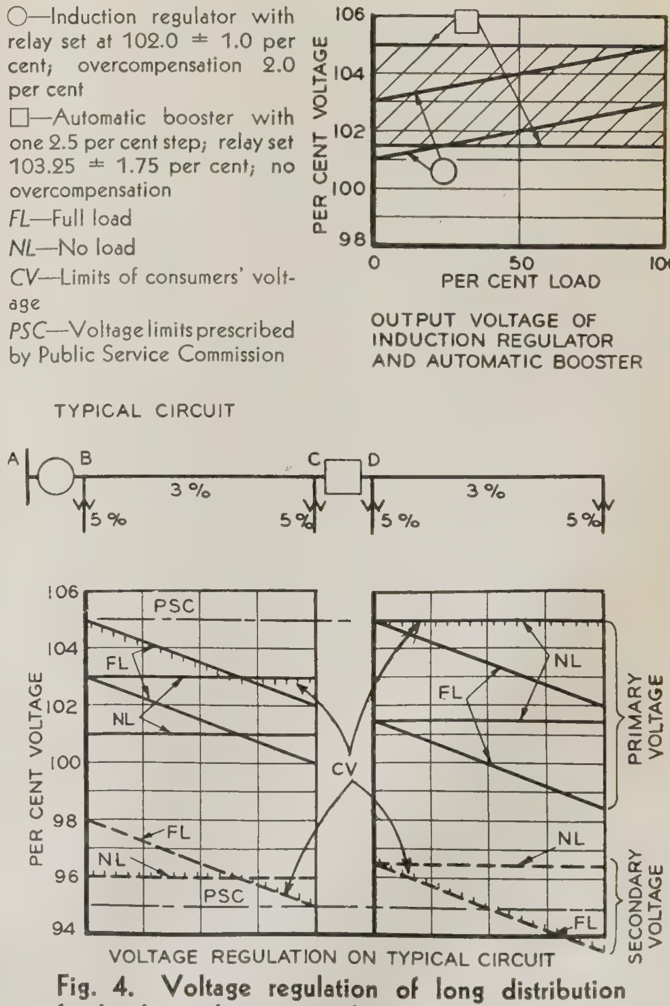
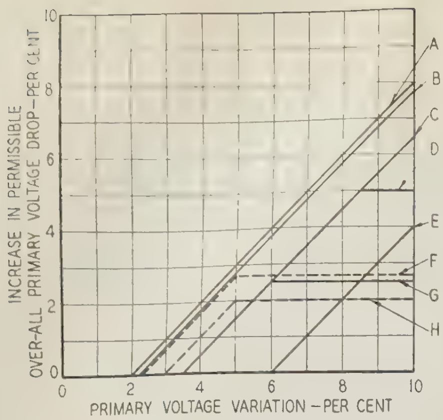


Fig. 4. Voltage regulation of long distribution feeder by induction regulator at substation and 2.5-per cent one-step automatic booster on pole



A—Induction regulator; no overcompensation
B to *H*—Automatic voltage booster with steps as follows:

	No. Steps	% Each Step
B	8	1.25
C	4	2.5
D	2	2.5
E	1 or 2	5.0
F	2	1.33
G	1	2.5
H	1	2.0

Fig. 5. Relative effectiveness of various automatic voltage boosters operating within a given range of primary voltage variation

raised to 4.5 per cent. In view of the lack of uniformity in the amount of overcompensation that can be allowed for transformer drop, however, the remainder of this paper will ignore this factor except where specifically indicated.

Methods for Improving Regulation

As circuits are extended and loading increases, there comes a time when the consumers' voltages cannot be regulated satisfactorily. There are 2 general classes of trouble: (1) flicker or fluctuating voltage caused by sudden changes in load, and (2) high or low levels of voltage. Where flickering exists, the solution must be determined by special analysis of the individual problem. Usually, however, the trouble is merely an excessive deviation in the peak load voltage. This paper will be restricted entirely to the latter type of trouble.

In general there are 3 methods for improving circuit regulation:

1. By rebuilding the circuit it is possible to reduce the voltage drop, either by installing larger conductors to reduce the impedance, or by arranging the circuit to reduce the current in the present conductors.

2. By transferring part of the load to other circuits, it is possible either to reduce the distance over which voltage must be maintained or to reduce the amount of load that must be regulated over the same distance.

3. By installing automatic voltage boosters, fixed boosters, series capacitors, or shunt capacitors, the over-all voltage drop in the existing circuit can be reduced to a value that permits satisfactory voltage regulation.

To a certain degree the voltage drop in a circuit can be reduced by substituting larger conductors over the same route. When 1/0 and 4/0 conductors have been installed, however, the practical limit to this method has been reached. If regulation troubles still are encountered, then the only solution remaining is to regulate for a feeding point somewhere near the center of the feeder area and to build a new primary branch feeding back along the main feeder. By this method the voltage drops in the primary branches within the feeder area can be cut to a fraction of their previous values and the circuit usually can be made to regulate satisfactorily. This method is called "rebuilding" in subsequent discussion.

There are places where rebuilding the circuit, as described in the preceding paragraph, is insufficient to satisfy requirements, or where that method already has been used to such an extent that further benefit is insignificant. Under these conditions it has been necessary to redesign the circuit, often dividing it and transferring part of it to a new circuit. This method usually requires a new feeder position in the distribution substation and considerable new line construction. It is, therefore, quite expensive and is avoided if possible until required for current-carrying capacity. There have been instances, however, where this method has been necessary to secure satisfactory voltage regulation.

There are several devices that can be used to improve the regulation of an existing circuit, such as series and shunt capacitors and voltage boosters. Unless there are special conditions to be corrected, such as flicker or low power factor, however, the series and shunt capacitors can be eliminated from consideration on the basis of cost. The fixed booster is really an ordinary distribution transformer connected as an autotransformer; its cost is low, but it is readily available only for a 5 or a 10 per cent boost which is too great for most applications. Furthermore, as its name implies, the boost is constant regardless of load conditions, and not more than one booster can be used on a line without exceeding the prescribed voltage limits. For these reasons, the fixed booster has lost favor in recent years. Development of the automatic voltage booster with $1^1/_4$ per cent and $2^1/_2$ per cent steps responsive to the voltage on the circuit has overcome these objections, however, and has opened up for general application the possibility of compensating the voltage drop in the circuit.

Operating Characteristics of Automatic Voltage Boosters

Various manufacturers are offering automatic voltage boosters controlled by voltage and by current, with a total range of from 2.5 to 10 per cent, with from 1 to 8 steps of from 1.25 to 10 per cent each and various combinations of fixed and automatic steps, and in current ratings from 6 to 208 amperes. There are also small induction regulators especially designed for installation on a pole. With such a variety of equipment available, it is necessary to determine first what characteristics are most desirable for this particular type of application.

In some respects, current control of these automatic boosters is attractive. It operates on the principle that the voltage drop in the line is directly proportional to the current flowing. The great spread between the current that does not produce an objectionable voltage drop and the current that does, makes it possible to use a very simple current-operated relay to control the amount of voltage boost. The relay must be set for each location, however, and the accuracy with which the voltage is regulated depends upon the consistency with which the distribution of load along the circuit is duplicated from

day to day. This limitation is overcome by voltage control, which actually governs the amount of voltage boost to maintain a certain predetermined voltage. The voltage range over which the relay operates is comparatively small, and it is necessary to use a relay especially designed for the purpose. This type of relay has been in use on induction regulators for some years, however, and is now perfected to such a degree that it can be applied without question to all automatic voltage boosters. These considerations indicate that voltage control should be used wherever it is desired to maintain voltage within close limits.

It has already been observed that the induction regulator maintains voltage only within ±1.0 per cent of the normal value, and the induction regulator may be said to operate in steps of less than 1.0 per cent. As the size of step is increased, the regulated voltage becomes less precise and the voltage relay contacts must be set farther apart to avoid too frequent operation of the voltage regulating device. Judging from experience with induction regulators, it is probable that the separation between the raising and lowering contacts of the relay should be about 1.0 per cent greater than the size of the step. Since the regulator output voltage band is a part of the total permissible variation in primary voltage, increasing the width of the band to permit the use of larger steps reduces the amount of voltage drop that can be permitted in the primary circuit between the regulator and the last transformer. The importance of this relationship is shown in figures 3 and 4 which show the circuit of figure 1 loaded so as to have a total primary drop of 6.0 per cent, half of which is compensated by means of a line-type voltage-regulating device. In figure 3 an induction regulator operating within a 2.0 per cent band is used and a drop of 3.0 per cent in the primary circuit to the last transformer gives a total variation in primary voltage of 5.0 per cent. Thus the limits, 100.0 per cent to 105.0 per cent, are maintained. In figure 4,

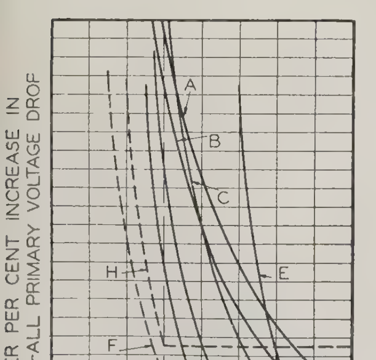


Fig. 6. Relative cost of various automatic voltage boosters operating within a given range of primary voltage variation

A—Induction regulator; no overcompensation; current capacity, 100 amperes

B to *H*—Automatic voltage boosters with steps as follows:

	No. Steps	% Each Step	Current Capacity, Amperes
B	8	1.25	100
C	4	2.5	63
D	2	2.5	84
E	1	5.0	70
F	2	1.33	75
G	1	2.5	70
H	1	2.0	100

however, a 2.5 per cent step voltage booster is used and the relay band must be increased to 3.5 per cent. With a drop of 3.0 per cent in the primary circuit from the booster to the last transformer, the primary voltage variation becomes 6.5 per cent. But the maximum permissible variation in primary voltage is 5.0 per cent; if primary voltage is to be regulated within the limits of 100 per cent and 105 per cent with a booster having 2.5 per cent steps, it is necessary to reduce the primary drop between the booster and the last transformer to 1.5 per cent, which means that the 2.5 per cent booster has increased the permissible over-all primary drop of the circuit from 3.0 per cent to 4.5 per cent, or only 1.5 per cent.

In this manner can be developed 2 rules governing the selection of boosters:

1. The size of the step determines the setting of the voltage relay which should have a band between the voltage-lowering and the voltage-raising contacts at least 1.0 per cent greater than the size of step. The difference between the permissible primary voltage variation and the regulated band establishes the maximum primary circuit drop beyond the booster that can be regulated within the limits.

2. The voltage range of the booster need not exceed the maximum primary drop established by rule 1, as any excess is rendered inoperative by the setting of the primary relay. Unless the voltage range of the booster is at least equal to the maximum primary voltage drop established by rule 1, however, the increase in permissible over-all primary voltage drop is limited to the voltage range of the booster.

To illustrate the application of these rules, a circuit is assumed on which it is desired to maintain the primary voltage between 100.0 per cent and 105.0 per cent. The loading is such that a booster of some sort is needed, and it is desired to use steps of 2.5 per cent. For this size of step, the lowering contacts of the primary relay should be set at 105.0 per cent and the raising contacts at 101.5 per cent in order to give a band of 3.5 per cent. According to the first rule, the increase in over-all primary voltage drop that can be regulated within the prescribed limits of primary voltage variation by one booster cannot exceed the difference between the allowable variation (5.0 per cent) and the regulated voltage band (3.5 per cent), or 1.5 per cent. The second rule states that the voltage range of the booster need not exceed 1.5 per cent. With 2.5 per cent steps a one step booster is adequate for this application. More than one step has no advantage because the voltage only needs to be raised from a minimum of 100.0 per cent on the input side to 101.5 per cent on the output side, or 1.5 per cent.

Supposing that 1.25 per cent steps had been designated for this application, then the contacts of the voltage relay should be set to give a band of 2.25 per cent. Subtracting this value from 5.0 per cent primary voltage variation leaves 2.75 per cent as the maximum increase in over-all primary voltage drop that can be regulated within the prescribed limits by one booster (rule 1). Any booster range over 2.75 per cent is adequate (rule 2); this calls for not less than 3 1.25 per cent steps and a 4 step booster might be applied, having a total range of 5.0 per cent but giving an increase of only 2.75 per cent in the permissible over-all primary voltage drop. In such a case it would be better, however, to install a 2 step booster with a total range of 2.5 per cent, thereby limiting the increase in permissible over-all

primary voltage drop to 2.5 per cent (rule 2), but effecting appreciable reduction in cost.

These 2 examples indicate a difference in the effectiveness of the several types of boosters even when applied under identical primary voltage limitations. The 2.5-per cent one-step booster added only 1.5 per cent to the permissible over-all primary voltage drop while the 2.5-per cent 2-step booster added 2.5 per cent. The effectiveness of several different types of boosters is indicated in figure 5, which compares the increases in permissible over-all primary voltage drop for the various units, within a given limit of primary voltage variation. The solid lines represent devices that are listed in the catalogs of the several manufacturers. The induction regulator and the 8 step regulator are clearly the most effective, but at 5.0 per cent primary voltage variation only a small portion of their 10.0 per cent voltage ranges is used. The 2.5 per cent step boosters are much less effective, and the 5.0 per cent step boosters are absolutely inoperative for primary voltage variations of less than 6.0 per cent, because of the voltage relay band required by the size of step. None of the boosters in catalogs is really suited to limits of primary voltage variation as low as 5.0 per cent, however, and several special ratings are proposed for this service. The effectiveness of 2.0-per cent single-step and 2.66-per cent 2-step boosters is shown by the dashed lines of figure 5.

With a method developed to measure the effectiveness of the several types of boosters, it is possible now to determine the relative costs. A current rating of 70 amperes is used as the basis of comparison, and standard kilovolt-ampere ratings of the several types of equipment were selected to carry this current. The price of each one of these in turn divided by the increase in permissible over-all primary voltage drop from figure 5 gives the cost per per cent increase shown in figure 6 for the corresponding per cent variation in primary voltage. This permits comparison of the cost of the several types applied under any

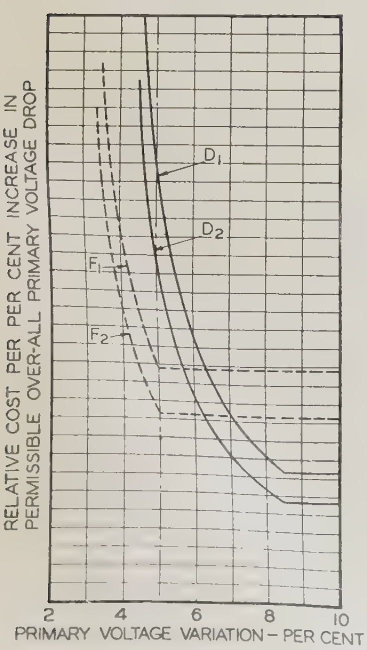


Fig. 7. Relative cost of voltage boosters having one fixed and one variable step compared with similar boosters having 2 automatic steps operating within a given range of primary voltage variation

	No. Steps	% Each Step	Current Capacity, Amperes
D_1	2—both automatic	2.5	84
D_2	2—1 fixed, 1 automatic	2.5	70
F_1	2—both automatic	1.33	75
F_2	2—1 fixed, 1 automatic	1.33	75

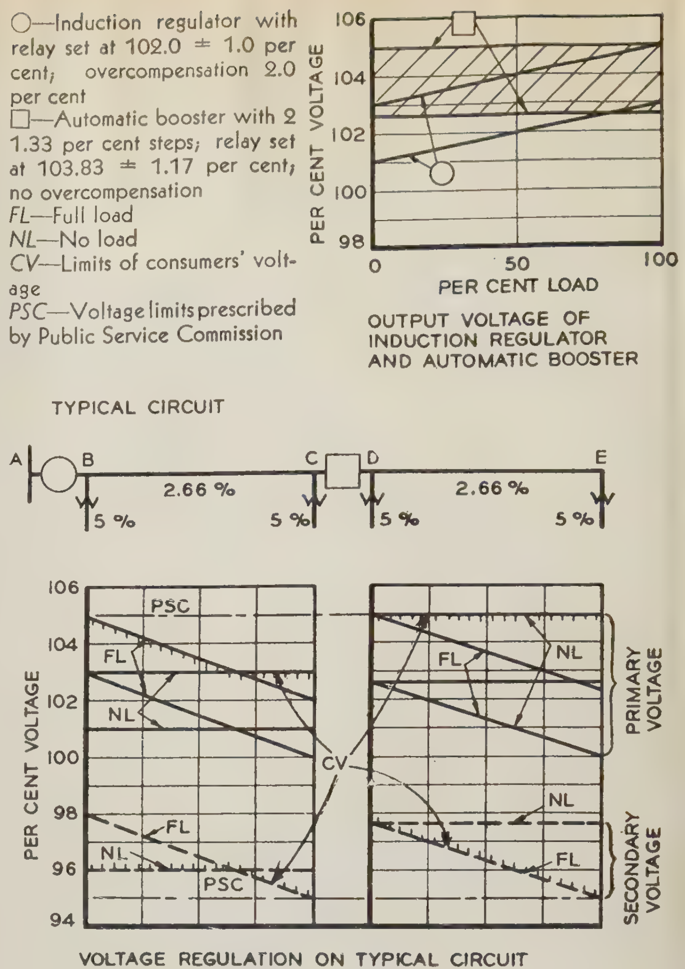


Fig. 8. Voltage regulation of long distribution feeder by induction regulator at substation and 2.66-per cent 2-step automatic booster on pole

prescribed limits of primary voltage variation. Again the types listed in the manufacturers' catalogs are shown as solid lines, and the special types as dashed lines. These curves show that the special types selected for 5.0 per cent primary voltage variation actually reduce the cost by some 30 per cent. When the difference in current carrying capacity is taken into account, there is little difference between 2.0-per cent one-step and 2.66-per cent 2-step boosters in cost or in operation, and it should make no material difference which is applied in the subsequent analysis. Inasmuch as there is some advantage in using as few installations as possible to accomplish the required result, however, the 2 step booster has been selected as the basis for the remainder of this paper. Figure 8 represents the operation of such a booster on a typical circuit, showing the proper relay settings and the limiting voltage drops that can be regulated by one booster. The 2.66-per cent 2-step booster increases the permissible over-all primary voltage drop by 2.66 per cent and maintains voltage within the 100.0 to 105.0 per cent limits.

The discussion thus far has been limited to suburban circuits where normal secondary design requires up to 5.0 per cent drop in distribution transformers,

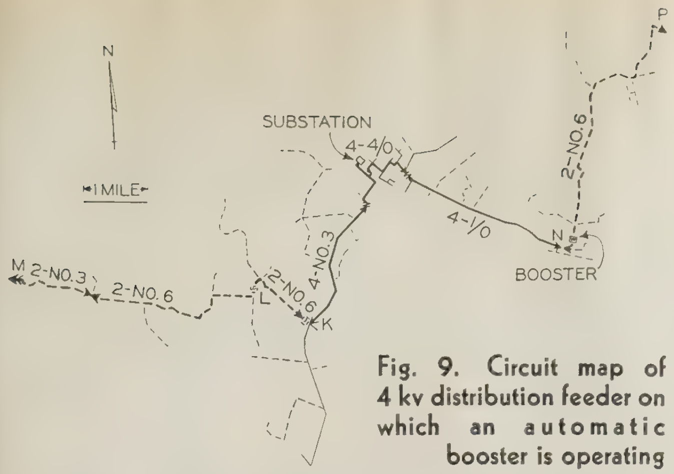


Fig. 9. Circuit map of 4 kv distribution feeder on which an automatic booster is operating

K and *L* indicate proposed locations of boosters; condition corrected without boosters by extending 2 phases to *L*

secondaries, and services. This leaves only 5.0 per cent for primary voltage variation and requires special boosters with small steps to attain a low cost. In some places, however, the circuit is entirely rural and has mostly individual transformers or small lightly loaded transformers and short secondary circuits with a total drop of about 2.5 per cent. With the same ±5 per cent deviation of service switch voltage, the primary voltage variation can be 7.5 per cent between the limits 105.0 per cent and 97.5 per cent. For this primary voltage variation, figure 6 indicates that a 5.0-per cent 2-step booster has the lowest cost. This condition probably is representative of many of the lines on which boosters have been applied, which accounts for the popularity of this type of equipment.

In some instances it is proposed to achieve the advantages of a 2 step booster by using the one step mechanism in conjunction with one fixed step of boost. This has grown out of the observation that the first step of 2 step boosters has shown a tendency to remain constantly in service. Many of the one step boosters sold have been used with one fixed step to give performance similar to the 5.0-per cent 2-step boosters of the preceding paragraph. The one step booster with one fixed and one automatic step is unquestionably cheaper than the 2 step booster which it replaces. The most obvious difficulty, overvoltage during the light load period, is avoided by the practice of operating substation feeder regulators to give about 102.0 per cent voltage at light load, which is sufficiently below the limit that a 2.5 per cent fixed boost may be used so long as the single phase load is well balanced on the 3 phases of the circuit. Another difficulty arises, however, in cutting such a booster in and out of service without interrupting service on the circuit. This can be done by means of fuses and a by-passing switch, but the complexity and cost of such a scheme tends to minimize the saving accomplished by using the one step instead of the 2 step booster. A comparison of the cost of a number of fixed-automatic step boosters with the cost of corresponding 2 step automatic boosters is given in figure 7, but only the full automatic device is used in the subsequent analyses of this paper.

For long suburban circuits, which are the basis of this analysis, it has been observed that primary voltage variation is limited to 5.0 per cent. The most suitable type of booster has been found to be one having a 2.66 per cent range with 2 automatic steps. With the amount of boost at any one location limited to 2.66 per cent, it is very probable that some circuits will require 2 or more boosters operating in cascade on each phase to take care of the drop. There might be a tendency toward frequent operation, or hunting, but it is probable that such trouble could be overcome by means of time delay. The physical limit would seem to be the increased tendency to flickering voltage caused by load fluctuations on the long line. There is no experience yet to indicate where the limit is, but it is assumed that up to 3 boosters per phase can be made to operate satisfactorily.

Application of Automatic Boosters

In the past, whenever the voltage drop in a circuit exceeded the allowable limit, it was necessary to rebuild the circuit in some way to reduce the drop. Now it is possible to install automatic boosters on the existing circuit to correct for the voltage drop and delay the rebuilding until it is justified by the current carried. When boosters of similar rating are used, however, it should be observed that the greatest benefit results from the first set, which increases the permissible over-all primary drop from 3.0 per cent to 5.66 per cent, or an increase of 89 per cent. The second set of boosters raises the permissible drop from 5.66 per cent to 8.32 per cent, which is numerically the same increase as in the first set but relatively only 47 per cent. The third set boosts the permissible drop to 10.98 per cent, relatively only 32 per cent. Using boosters instead of rebuilding the circuit means carrying the load current on smaller

Fig. 10. Automatic voltage booster installation

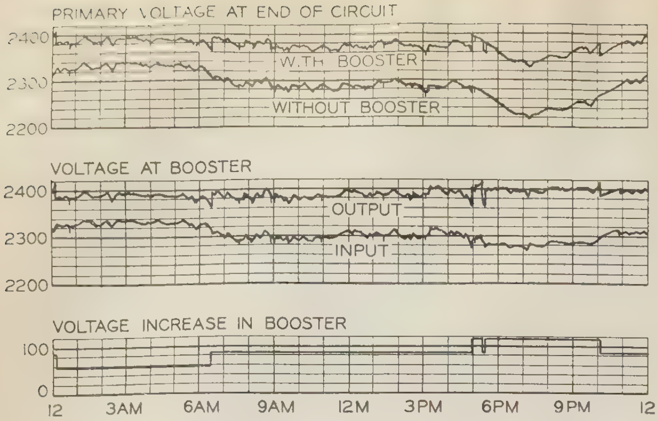


Fig. 11. Voltage charts showing effect of automatic voltage booster

conductors and usually causes greater losses. Each time a set of boosters is installed this difference in losses increases. The greatest gain is secured from the first set of boosters and less from each succeeding set until a point is reached at which it is not economical to install more boosters. This circumstance leads to the conclusion that 3 boosters per phase is about as many as can be justified.

Boosters have one material advantage over circuit rebuilding as a means to maintain voltage within the prescribed limits. They are small and substantial, readily installed and just as readily removed when they are no longer needed. When the boosters are removed from one location, they can be put in service in a new location on some other line. In short, they have the same high reclaim value and flexibility as the distribution transformer and can be moved from place to place as changes in circuits and loading require.

The application of boosters tends to follow a distinct cycle such as the following:

1. A line is built to serve a light scattered load. Regulation at the substation provides satisfactory voltage.

2. The load grows until the voltage toward the end of the line falls below the minimum limit. Small automatic boosters are installed at the point where the primary drop is about half of the total primary drop.

3. The load grows more until even with the boosters the voltage is too low. A second set of boosters of larger capacity is installed at the point where the primary drop is $^1/_3$ of the total primary drop; the first set is moved out on the circuit to the point where the primary drop is $^2/_3$ of the total. In this way the small boosters are moved to a point where they can still carry the current and larger boosters are installed where the current is heavier.

4. The load grows still more and a third set of large boosters is installed at the point where the primary drop is $^1/_4$ of the total primary drop if the third set can be justified economically in place of line rebuilding. The first and second sets are moved farther out on the circuit where the current is within their rating.

5. The load exceeds the current carrying capacity of the circuit and steps are taken to increase the capacity. The boosters then are reclaimed and used on other circuits.

Field Experience

The Duquesne Light Company has one 4 kv circuit that is particularly interesting in that each of the 2 main branches recently has been studied and improved on account of low voltage. This circuit is shown in figure 9 with 3 phase sections indicated by solid lines and single phase sections by dashed lines. The main feeder from the substation to the points of low voltage is shown by heavier lines to bring out more clearly the conditions of the problems.

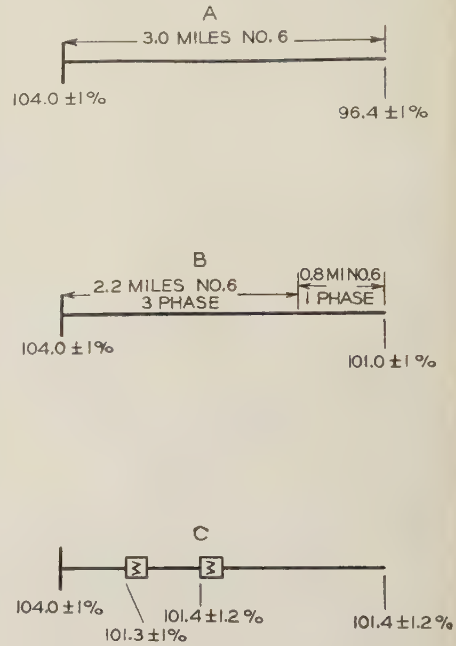


Fig. 12. Economic comparison between circuit rebuilding and installing boosters to improve voltage on a 3-mile single-phase tap at the feeding point of a 3-phase 4-kv distribution feeder

Length of circuit to furthest transformer —3 miles

Load—25 amperes, uniformly distributed

Primary voltage at beginning of circuit —104.0 ± 1.0 per cent, not compensated for distribution transformer drop.

Feeding point is at the left. Percentages refer to primary voltage

A—Initial conditions

B—Change 2.2 miles of single phase to 3 phase line and transfer load; additional investment plus increased losses capitalized—$1,070

C—Install 2 2.66 per cent automatic boosters; additional investment plus increased losses capitalized—$1,190

The feeder regulators at the substation are operated to supply voltage within the required limits to the suburban town in which it is located and to give a pothead voltage of approximately 2,400 volts (104.4 per cent nominal voltage) to neutral on each phase during the period of circuit peak load. By far the greater portion of the load is carried on the easterly branch, and the dividing point is so near the substation that the other branch has no appreciable influence and can be neglected for the present.

This easterly branch of the circuit consists of about 4 miles of 4/0 and 1/0 3 phase line with a single phase rural extension running 4.4 miles beyond the end of the 3 phase line. In the village at the end of the 3 phase portion of the circuit, N, the primary voltage drops to 98.7 per cent (2,270 volts) for short periods in the evening, which is too low to insure 95.0 per cent voltage at all service switches with normal secondary system design. But the single phase extension has about 2.4 per cent additional drop which gave 96.3 per cent voltage (2,216 volts) on the primary at the end of the circuit, P, and voltages probably as low as 92.5 per cent to the

consumers in that vicinity. Here was a case where some 2.5 per cent increase in voltage was required to meet the limits of the Public Service Commission. Converting the single phase extension to a 3 phase line could not raise the voltage at P enough to meet the established limits, and extensive rebuilding of the 4/0 and 1/0 portion of the circuit would have been necessary. The situation was ideal for the

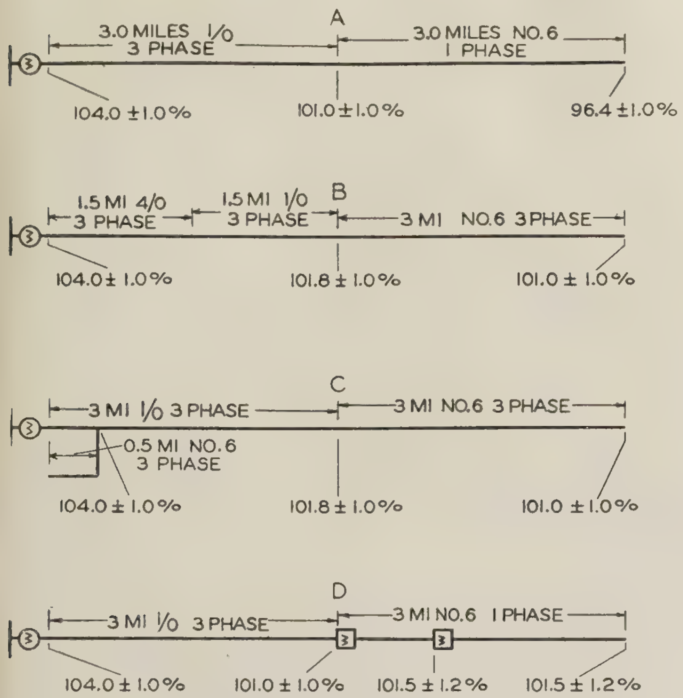


Fig. 13. Economic comparison between circuit rebuilding and installing boosters to improve voltage on a 3-mile single-phase tap at the end of a 3-phase 4-kv distribution feeder

Length of 3-phase circuit to beginning of single phase extension—3 miles; Load—65 amperes per phase, uniformly distributed. Length of single phase extension—3 miles; load—15 amperes, uniformly distributed. Primary voltage at first transformer on 3 phase circuit—104.0 ± 1.0 per cent; not compensated for distribution transformer drop. Feeding point is at the left. Percentages refer to primary voltage

A—Initial conditions

B—Change single phase to 3 phase line and increase wire size in main circuit; additional investment plus increased losses capitalized—$5,415

C—Change single phase to 3 phase line, move feeding point to 0.5 mile from substation and feed back; additional investment plus increased losses capitalized—$2,205

D—Install 2 2.66 per cent automatic boosters; additional investment plus increased losses capitalized—$1,160

experimental installation of an automatic voltage booster at N.

At that time the numerous types of equipment discussed hereinbefore were not on the market, and arrangements were made with one of the manufacturers to develop a booster for this application. This booster has a rating of 100 amperes at 2,400 volts and varies the voltage over a 10 per cent range in 8 1.25 per cent steps controlled by the same type of voltage relay as is used on induction regulators. The booster was installed as shown in figure 10 and was adjusted to maintain an output voltage band of 103.9 ± 1.1 per cent (2,390 ± 25 volts). Simplified types of equipment now on the market would give adequate voltage correction at lower cost, but this installation was set up in accordance with the principles discussed in preceding paragraphs and has yielded experimental data that apply equally well to the less expensive devices.

Recording voltmeters were connected to the primary circuit on both sides of the booster and at the end of the circuit in order to find what improvement had been accomplished by installing the booster. Since these charts cannot be compared readily in their original form, they have been transcribed in rectangular co-ordinates and superposed to give figure 11. The input and output voltages of the booster are shown on the middle chart, and the difference between these gives the voltage increase in the booster which is plotted on the lower chart. The upper chart shows the actual recorded voltage at the end of the primary circuit and an estimate of the voltage that would have been recorded if there had been no booster. Thus a complete record of the operation of this booster during a representative 24 hour period is given by this one diagram. It may be interesting to note that 2 steps of the booster remain in the circuit continuously and the third and fourth steps operate during the load periods to maintain the output voltage within the band 103.9 ± 1.1 per cent. The improvement in primary voltage at the end of the circuit is obvious, and the service switch voltage

Length of circuit to furthest transformer—3 miles. Load—150 amperes per phase, uniformly distributed. Primary voltage at first transformer—104.0 ± 1.0 per cent; not compensated for distribution transformer drop. Feeding point is at the left. Percentages refer to primary voltage

A—Initial conditions

B—Move feeding point to 1.5 miles from substation and feed back; additional investment plus increased losses capitalized—$6,560

C—Build second circuit to divide load; additional investment plus increased losses capitalized — $14,200

D—Install 2 sets of 2.66 per cent automatic boosters; additional investment plus increased losses capitalized—$4,650

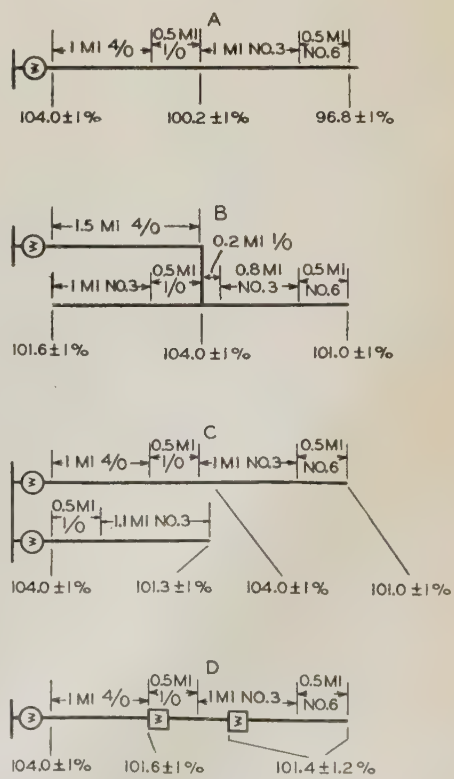


Fig. 14. Economic comparison between circuit rebuilding and installing boosters to improve voltage on a 3-mile 3-phase 4-kv distribution feeder

Table I—Effect of Time Delay Setting on Number of Tap Changes

Time setting, seconds	15	30	60
Length of test, hours	22.5	48.0	45.0
Number of tap changes	79	61	14.0
Tap changes per 24 hours	84	30	7.5

is improved correspondingly to an estimated minimum of 97.7 per cent (112.4 volts).

This booster was provided with a time delay relay variable from 2 to 60 seconds. Inasmuch as the proper time delay to limit the number of tap changes and still maintain good voltage has been a debated subject, a test was conducted to determine the effect of various time settings. The voltage charts showed no material difference in regulation for the several settings, but there was a decided increase in the number of tap changes for short time delays. The results are given in table I.

All these data were taken with a voltage band of 2.2 per cent between the raising and lowering contacts. As the steps were 1.25 per cent, this left a margin of 0.95 per cent in the relay to allow for small variations of voltage. Other settings were not tried, but it is possible to estimate from the input voltage curve of figure 11 the effect of different relay settings on the number of tap changes. Table II shows that increasing the margin of the spread between the relay contacts over the size of step materially reduces the number of tap changes.

Inasmuch as the conditions to which these data apply can be considered fairly representative of circuits on which boosters should be used, it seems reasonable to derive from them the policy to be followed in other booster installations. In regard to time delay, it is clear that the longest possible setting should be used. The Pennsylvania Public Service Commission permits voltage deviations exceeding ± 5 per cent for durations of less than 60 seconds. Accepting this as the limit and allowing a few seconds for the tap change, it seems advisable to adopt 50 seconds as a desirable time delay. A different situation limits the relay band width, however, as increasing the margin spreads the voltage range within which the booster operates and reduces the amount of primary drop that can be compensated by the booster. Hence, although the reduction in tap changes achieved by the increased margin is attractive, it is essential that the margin be kept as small as possible; therefore, 1.0 per cent has been selected tentatively as an acceptable figure.

Although the conditions of this installation differ slightly from the general analysis, the duty is sufficiently similar to serve as a thorough test of the automatic voltage booster in service and to indicate the technical soundness of its application on typical distribution circuits.

Conditions Unfavorable to Boosters

The circuit shown in figure 9 also had a low voltage problem on the southwesterly branch for which automatic boosters were considered as a possible solution and discarded in favor of line construction. This branch taps off the main feeder near the substation and runs in a southerly direction with 4 number 3 conductors most of the way. At point K, nearly 3 miles from the main feeder, a single phase rural circuit extended from phase C westward for more than 5 miles. This extension served about 50 per cent of the total transformer capacity on the entire southwesterly branch. Even with all the single phase load on the remainder of the branch fed by phases A and B, this condition caused a heavy neutral current in the 3 phase portion of the branch and appreciable displacement of the neutral voltage. Under evening peak load conditions the C phase voltage even on the 3 phase circuit at K dropped to 100.0 per cent (2,300 volts) and the regulation of the long single phase extension reduced the primary voltage at the extreme end, M, to 92.3 per cent (2,123 volts). With the light loading and short secondaries on this circuit, it is likely that the voltage drop in transformers and secondaries did not exceed 2.5 per cent, but even so the service switch voltage must have dropped to 89.8 per cent (103.3 volts).

To meet the established lower limit of 95 per cent voltage required an increase of at least 5.2 per cent in primary voltage, and it had been proposed to install 2 automatic boosters—one near K and the other near L. Further study showed, however, that extending the A and B phases approximately 6,500 feet to L would permit the transfer of enough load substantially to eliminate the neutral current in the 3 phase portion of the circuit. The C-phase voltage at K increased to 102.9 per cent (2,367 volts) and the service switch voltage at the end of the 5 mile extension, M, increased to 96.4 per cent (110.9 volts). This rebuilding decreased line losses materially and

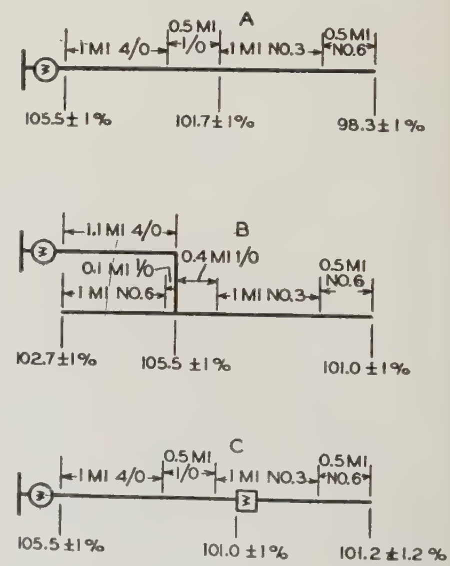


Fig. 15. Economic comparison between circuit rebuilding and installing boosters to improve voltage on a 3-mile 3-phase 4-kv distribution feeder with 1.5 per cent overcompensation for distribution transformer drop

Length of circuit to furthest transformer—3 miles. Load—150 amperes per phase, uniformly distributed. Primary voltage at first transformer—105.5 ± 1.0 per cent; compensated 1.5 per cent for distribution transformer drop. Feeding point is at the left. Percentages refer to primary voltage

A—Initial conditions

B—Move feeding point to 1.1 miles from substation and feed back; additional investment plus increased losses capitalized—$3,760

C—Install one set of 2.66 per cent automatic boosters; additional investment plus increased losses capitalized—$2,180

improved the facilities for taking on load growth, all with some 37 per cent less investment than would have been required for the 2 automatic boosters.

In another instance the automatic voltage booster was considered as a means to improve the voltage at a mining village fed by a 5-mile 3-phase 4-wire circuit. Voltage charts showed a pronounced voltage fluctuation, however, which would have caused too frequent operation of the boosters. This device was ruled out, and the voltage condition will be corrected by means of a series capacitor applied to reduce the voltage fluctuation and simultaneously to raise the steady state voltage. The automatic boosters would have been less expensive, but the conditions were such that the application probably would not have been successful.

These 2 cases are cited to show that automatic voltage boosters should not be applied indiscriminately. Each problem must be studied carefully—first, to make certain that the booster is the most economical solution, and second, to guard against operating conditions that the booster cannot satisfy.

Economic Comparison of Boosters and Conventional Rebuilding

After studying the operating conditions and limitations covering the application of automatic voltage boosters on distribution circuits, it is in order to investigate the economics. There are 2 major problems to consider: (1) whether boosters can be used to reduce the cost of rebuilding existing circuits on which the regulation is found to be unsatisfactory, and (2) whether boosters can be used to reduce the cost of a feeder serving a constantly growing load by simplifying the circuit alterations necessary to maintain voltage within the specified limits. For each problem the present solution depends upon circuit rearrangement and larger wire. Except on the shortest circuits, these changes are required by regulation long before the load reaches the current carrying capacity of the circuit. The automatic voltage booster offers the alternative of using the existing circuit and correcting the voltage by the action of the booster.

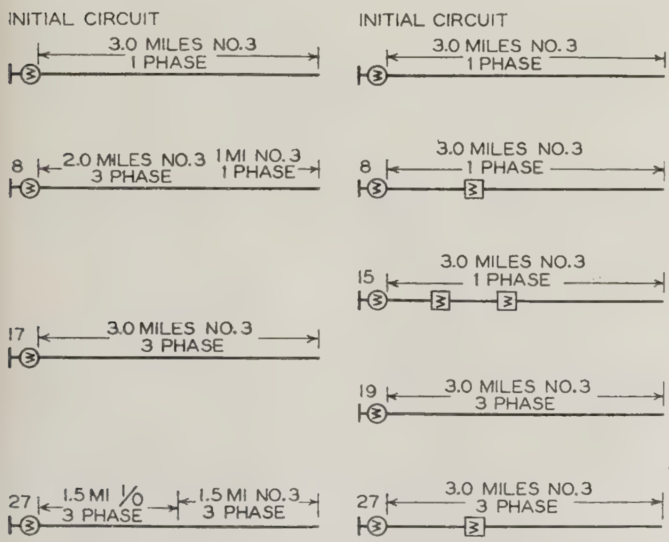
Table II—Effect of Voltage Relay Band Width on Number of Tap Changes With Time Setting of 60 Seconds

Relay band width in per cent of full voltage	1.00	1.10	1.25	1.38
Size of step in per cent of full voltage	1.25	1.25	1.25	1.25
Relay margin in per cent of full voltage	0.75	0.95	1.25	1.51
Tap changes during 24 hours	8	6	4	2

Four typical distribution circuits with poor voltage regulation are discussed in the following paragraphs. One or more solutions of the conventional type and one solution using automatic voltage boosters are given for each circuit. The diagrams are simplified by eliminating all transformers and secondary circuits and showing only the primary circuit from the first transformer to the transformer on which the low voltage conditions exist. Primary voltage is shown at certain points, and it is the purpose of all solutions to keep this voltage, including the regulator tolerance, within the limits 105.0 and 100.0 per cent.

The first circuit figure 12, represents a long single phase extension from the feeding point of a regulated 3 phase circuit. This is considered first because it is inexpensively corrected by merely converting as much of the circuit to 3 phase line as is necessary to meet the voltage specifications. With no change in the wire size, this method offers the possibility of reducing the voltage drop to $^1/_6$ of the original drop. Rebuilding is somewhat less expensive than boosters in this particular case and would seem to be the better solution unless there is good reason to believe that the low voltage condition is temporary, in which case the high reclaim value of the boosters would justify the larger investment.

The second circuit, figure 13, is more nearly representative of the usual single phase extension. As a matter of interest, it is very similar to the circuit conditions under which an 8 step booster was installed. This line has a 3 phase main circuit having satisfactory voltage at all points, and a single phase extension from the end of the 3 phase section with unsatisfactory voltage. Changing the entire extension to 3 phase line does not solve this problem because of voltage drop in the 3 phase section, and it is necessary to make changes also in the main circuit. Under these conditions the automatic boosters are materially



Conventional Rebuilding

Year*	Load Current (Single Phase)
0	8.7
8	18.5
17	43.9
27	114.3

2.66 Per Cent Automatic Boosters

Year*	Load Current (Single Phase)
0	8.7
8	18.5
15	36.3
19	53.5
27	114.3

* Indicated by figures at left of diagrams

Fig. 16. Periodic alterations on 3-mile 2,300-volt single-phase circuit to maintain primary voltage within limits of 105 and 100 per cent for load growth of 10 per cent per year

less expensive and would seem to be the unquestionable solution.

The third circuit, figure 14, is a 3 phase circuit with wire sizes tapering from 4/0 to number 6. The conventional solution ordinarily would be to establish a feeding point near the center of the load area to feed back with a branch parallel to the main feeder. The voltage drop in the main feeder is compensated by the feeder regulators set to maintain voltage at the feeding point, and the effect is to cut the voltage variation within the load area to about $^1/_4$ of its original value. The same improvement in voltage is secured by installing a total of 6 2.66 per cent boosters, 2 per phase, in the original circuit. The latter solution is less expensive as well as more flexible in adaptability to future changes.

The fourth circuit, figure 15, is identical with the third except that the tendency for load to increase simultaneously on all transformers permits 1.5 per cent overcompensation. Thus the upper limit of primary voltage is raised to 106.5 per cent during peak load, which allows greater variation in primary voltage and makes less extensive changes necessary to correct the low voltage condition at the end of the circuit. Even so, the automatic voltage boosters correct the voltage condition at appreciably lower cost.

From these examples, it is concluded that the automatic voltage booster reduces the cost of correcting a low voltage condition on any feeder of more than average length where correction otherwise would require the installation of large conductors in the 3 phase portion of the circuit. Low voltage on a single phase extension sometimes can be corrected by converting the extension to 3 phase circuit, however, and in such cases boosters should be used ordinarily only where there is reason to believe that within a few years time changes in loading or system design will eliminate the low voltage condition and permit the boosters to be removed to some other circuit. In all cases boosters should be used only where the current carrying capacity of the conductors is ample for the load to be carried.

The history of a distribution feeder is usually one of a constantly increasing load which occasionally exceeds either the current carrying capacity or the voltage regulation limits and requires circuit rebuilding or the installation of new circuits. It seems, therefore, that the real test of the economic value of the automatic voltage booster is whether its use to simplify these changes will result in a lower cost of serving such a load. No 2 cases are alike, but most of them have certain similar characteristics. The original circuit is laid out to reach consumers along a certain route, often a highway, at a time when the consumers are scattered and have small demands; the problem then is to feed these consumers at the lowest cost, and the circuit is built with number 3 to number 6 conductors, single phase. As time passes, new consumers are connected on this circuit and old consumers increase their demands until the voltage regulation exceeds the allowable limits and improvements become necessary.

Two courses are open. The one commonly used today calls for either replacing the original small conductors with larger conductors or extending the other 2 phases gradually until the entire circuit is 3 phase; the latter probably results in greater economy because of the increase in circuit voltage from 2,300 to 4,000 volts. The other course makes

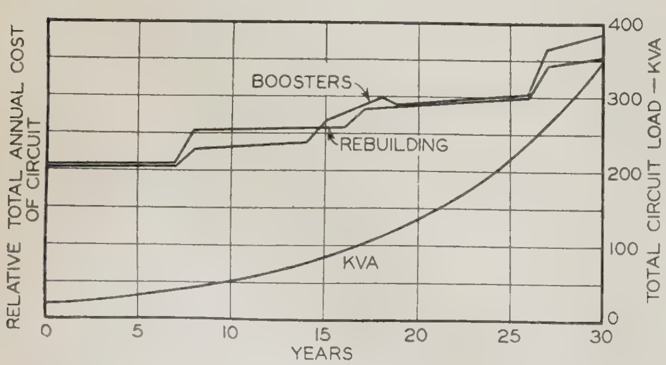
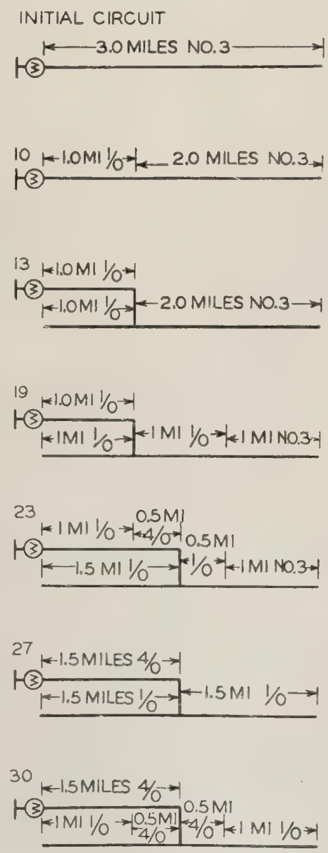


Fig. 17. Relative total annual cost of serving a load growing 10 per cent per year on a 3-mile 2,300-volt feeder initially single phase with 2 No. 3 conductors

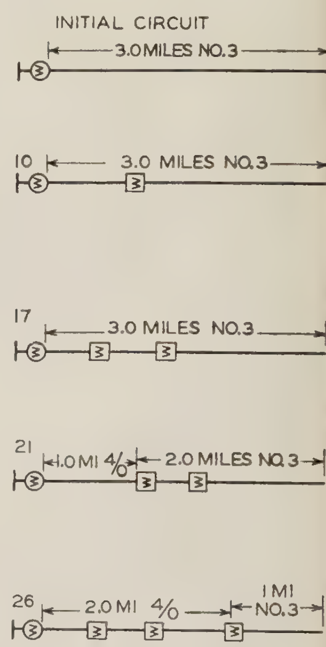
Limits of primary voltage—105.0 and 100.0 per cent



Conventional Rebuilding

Year*	Load Current
0	14.6
10	37.8
13	50.4
19	89.9
23	131.5
27	193.3
30	257.4

* Indicated by figures at left of diagrams



2.66 Per Cent Automatic Boosters

Year*	Load Current
0	14.6
10	37.8
17	55.1
21	108.6
26	175.5

Fig. 18. Periodic alterations on 3-mile 4-kv 3-phase circuit to maintain primary voltage within limits of 105 and 100 per cent for load growth of 10 per cent per year

use of automatic boosters to correct the voltage and so delay circuit reconstruction until it can be justified economically. These 2 methods have been applied to a typical regulated single-phase 2,300-volt circuit 3 miles long with a load initially of 20 kva and growing at the rate of 10 per cent per year for 30 years. To keep the primary voltage within the limits of 105 to 100 per cent, several changes are necessary. The steps are indicated in figure 16. The total annual cost of this circuit, including taxes, return on investment, operation and maintenance, losses, and depreciation based upon the life in service is plotted year by year for each method in figure 17. Comparison indicates very little difference between the 2 methods, and the logical decision would favor the change to 3 phase circuit because of the ability to serve power loads. This confirms the conclusion drawn from the static comparison of figure 12 that

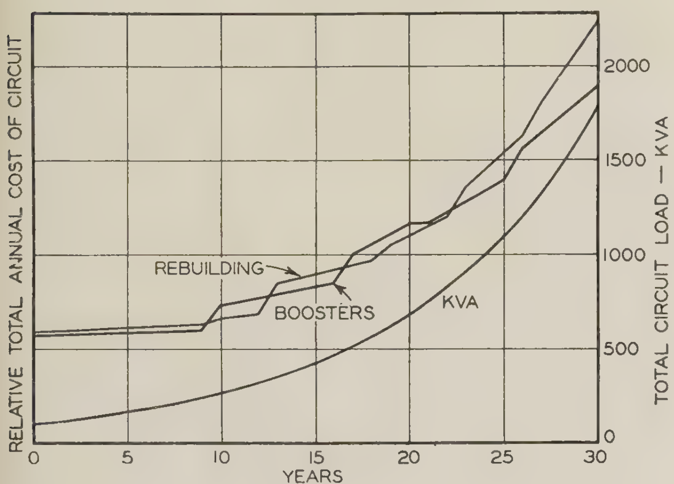


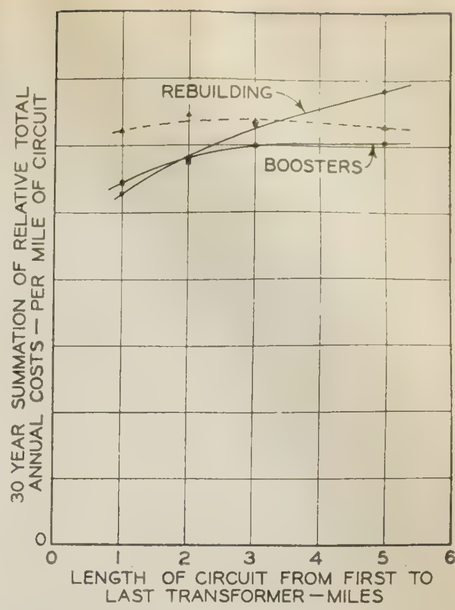
Fig. 19. Relative total annual cost of serving a load growing 10 per cent per year on a 3-mile feeder initially 4-kv 3-phase with 4 No. 3 conductors

Limits of primary voltage—105.0 and 100.0 per cent

automatic voltage boosters should be applied under such conditions only where there is good reason to believe that the unsatisfactory voltage conditions are temporary.

After the change to 3 phase circuit has once been made, however, the situation is much different. Voltage improvement by the conventional method requires extensive alterations such as increasing the conductor size, establishing a feeding point near the load center and building a heavy main feeder to that point, or building a new feeder to divide the load. The automatic booster however, permits use of the existing conductors until alterations are economically advantageous or dictated by current carrying capacity. These 2 methods have been applied to a typical regulated 3-phase 4,000-volt circuit 3 miles long with a load initially 100.5 kva and growing at the rate of 10 per cent per year for 30 years. Again the primary voltage is kept within the limits of 105 per cent and 100 per cent and periodic changes are required as indicated in figure 18. The

Fig. 20. Summation of relative total annual costs during 30 year period of growth at 10 per cent per year from an initial load of 100.5 kva to show the effect of circuit length upon the savings possible by installing boosters



Solid curve marked "boosters" indicates savings possible with boosters applied to obtain economic loading of the circuit. Broken curve shows increased cost with boosters applied to load the circuit to current carrying capacity

total annual cost, including taxes, return on investment, operation and maintenance, losses, and depreciation based upon the life in service, is plotted year by year for each method in figure 19. Until the twenty-third year there is no appreciable difference; then the cost of rebuilding begins to rise above the cost of voltage correction with boosters. Reference to figure 18 reveals that this rise coincides with the use of 4/0 conductors in the conventional rebuilding. From this point on the use of boosters effects an appreciable reduction in annual cost.

Realizing that long circuits are generally more difficult to regulate and more expensive to improve, one would expect that boosters might accomplish even greater savings on them. Conversely, it would seem probable that boosters cannot be justified on short circuits. Comparisons similar to the one described for 1, 2, and 5 mile circuits show these assumptions to be correct. The results of the comparisons are expressed in terms of the total annual cost during the 30 year period and are plotted in figure 20 to indicate the relationship between circuit length and the savings possible with boosters.

In deriving these results, it was found necessary to apply boosters somewhat sparingly to secure the greatest savings. There is a tendency to install more and more boosters and to retain the original conductors until the load grows to the point where increased current carrying capacity is required. This procedure raises the current far beyond the economic point for the conductors and results in excessive losses with consequent increase in annual cost as shown by the dashed line in figure 20.

It was found advisable to replace small (number 3) conductors with large (4/0) conductors instead of installing automatic boosters to improve the voltage wherever the average peak-load current for a half mile or mile section exceeded approximately 50 per cent of the current carrying capacity. This policy

may appear somewhat extreme until it is seen that the comparison is not between conductors alone, but between small conductors with boosters and large conductors without boosters. Because of the possibility of instability and the lack of operating experience, the number of boosters in cascade has been limited to 3; but it now appears probable that economics may set a limit in many cases where less than 3 boosters are used.

The load growth comparisons confirm the conclusion derived from static load comparisons that the automatic voltage booster reduces the cost of correcting a low voltage condition on any feeder of more than average length where correction otherwise would require the installation of large conductors in the 3 phase portion of the circuit. The comparisons show, moreover, that such use results in lower accumulated annual cost for the feeder during its period of development. However, the greatest economy in most cases results not from the use of boosters alone, but from the judicious combination of boosters and the rebuilding of circuits.

A New Thermal Fuse for Network Protectors

Fuses made of copper that have been used as additional protection for transformers in low voltage networks in the event that the network protector should fail to operate may blow too quickly on brief overloads, and fail to blow on long-sustained overloads of lesser magnitude. By the combination of a fusible alloy of low melting point and copper blocks that delay the rate of temperature rise the fuse described in this paper provides a time-current characteristic which more nearly approaches the ideal.

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TRANSFORMERS in low-voltage a-c networks are usually connected to the low-voltage network grid through an automatically controlled air-break circuit breaker, known as a network protector. Network protectors are controlled by directional relays so as to trip only on currents feeding back in the reverse direction such as would result from a short circuit in the transformer or the primary feeder. Most network relays are sufficiently sensitive to operate on the "backfeed" exciting currents of transformers when the primary feeder is disconnected from its source of supply. The relays are also arranged to close the protector when the transformer is able to feed current toward the network. If the protector fails to trip on current feeding back into a short circuit on a primary feeder, the heavy current may quickly damage the transformer, network protector, and even adjacent network mains. To prevent this it is customary to install fuses in series with the network protector as "back up" protection.

When the network protector does fail to trip on "backfeed" current, it is desirable for the fuse to clear the fault as quickly as possible thereafter. However, fuses are nondirectional and will blow equally well on power flow toward the network. Premature blowing in the latter case is highly undesirable. The ideal network protector fuse, therefore, is one that will blow only as a last resort to prevent damage to the transformer, network protector, and adjacent network mains.

The copper link, type of fuse (*A* and *B* in figure 1) has been used in Brooklyn, N. Y., since the initial network installation in 1927. The network transformers are rated 3 phase, 500 kva, 1,333 amperes, and 125/216 volts. The minimum blowing currents of the fuses *A* and *B* are respectively $2^1/_2$ and 3 times the transformer rating. This size of fuse represents a compromise between conflicting requirements. The minimum blowing current is too high, because currents just below this value can overheat the transformer in from 7 to 10 minutes, which does not allow sufficient time for the emergency crew to locate and clear the trouble. The fuse also operates too quickly on heavy currents, occasionally blowing on network faults and in several instances blowing before the protector could operate on "backfeed" currents. The copper link fuse can be expected to operate before the protector on nearby primary faults when the relays are slowed down by the reduced voltage and where an unusually heavy network grid allows more than 10,000 to 12,000 amperes to feed back.

Fuse Operation on Reversed Power Flow

The Brooklyn network is a heavy grid made up of 500,000 circular mil mains and will average about 10,000 amperes per phase feeding back through the

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fuses to a 3-phase short circuit on a primary feeder. Cases have occurred where unusually high "backfeed" currents have blown the fuses before the protector could open. Conversely, the fuses may not even be able to clear all primary fault conditions if the protector should fail to trip. For example, a reversed flow through the transformer, which is connected in delta on the primary side, into a line-to-line short circuit on a primary feeder will draw average currents of 5,000, 5,000, and 10,000 amperes through the 3 fuses. After the fuse with the largest current blows, the other currents will drop below 3,000 amperes and will not blow the fuses unless the fault spreads into the other phase. If primary short circuits were the only consideration the ideal fuse would blow on any reversal of power flow exceeding the transformer rating and yet would have thermal capacity enough to allow the network protector the opportunity to trip first.

Fuse Operation on Network Loads

It has generally been the opinion that network faults will burn clear provided sufficient fault current is available, but that the premature blowing of fuses, by reducing the fault current, tends to make faults hang on longer and spread over greater distances. Analysis of experience during 8 years in operating a low-tension a-c network, which has grown to cover about 25 square miles supplied by more than 1,000 network units, indicates that there are so many variable conditions involved that this relationship is somewhat obscured. Although the copper link fuses have blown in very few instances, it is thought that in at least one instance the blowing of the transformer fuses caused the trouble to travel about 1,000 feet along a network boundary. It is desirable to fuse high enough to prevent unnecessary blowing on network short circuits, thus avoiding fuse replacements and low voltage resulting from blown fuses.

Fuses that blow too readily are subject to the danger of "cascading" or progressive blowing. For example, a local fault might blow the fuses on several surrounding transformers, leaving both load and fault currents to be supplied by more distant transformers. The latter, being overloaded, also blow fuses and so on until the entire area is dead. However, calculations and experience indicate that the copper link fuses used on the Brooklyn network are not subject to cascading from local secondary trouble.

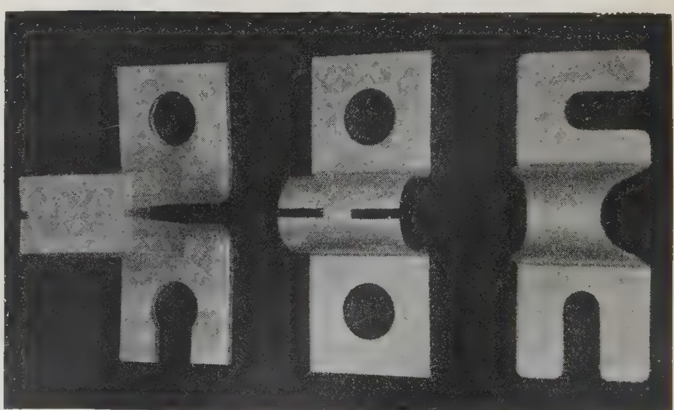
If a network area is completely dead, the problem of starting up is, of course, dependent upon having sufficient capacity in boilers, generators, or interconnection to other plants to carry at least the normal load, together with busses, feeders, and transformers to distribute it. The initial connected load includes the starting currents of domestic refrigerators, oil burners, etc., and of such other motors as are not automatically or manually disconnected, with the result that the total inrush of current may be more than double the normal load. It is also probable that the shutting down of the network would be accompanied by heavy load transfer throughout the network, with reversal of power flow through some network transformers tripping out their network protectors and possible blowing some fuses. In starting up a large network area, it will probably be impracticable to close these protectors in advance by hand and it may not be possible to energize all primary feeders to the area simultaneously. Consequently, the first transformers energized will be greatly overloaded, and there is danger of blowing not only their fuses but also fuses on other transformers as fast as they are energized and connected to the network. The problem is to bridge over the temporary period of high currents resulting from the starting of motors, etc., and overloads resulting from inability to energize simultaneously all feeders and close all network protectors that are open. Therefore, starting operations will be greatly simplified and made more certain by means of fuses having a long time delay.

Required Fuse Characteristics

The copper link fuses have excessive losses at the rated load of the transformer and the heat from this source raises the temperature in the enclosed compartment of the network protector to an excessive degree. Inasmuch as this tends to reduce the permissible loading of the network protector, it is obviously desirable to reduce fuse losses.

The requirements for a fuse to satisfy all conditions conflict to some extent and compromises are necessary. The minimum current to cause blowing must be high enough to avoid blowing on legitimate overloads, and yet low enough to insure blowing when necessary as a last resort to avoid further damage. Also, the fuse should take advantage, if possible, of the greater overloading permissible when the equipment starts cold as compared to conditions when the equipment is already hot.

The thermal capacity of the fuse should be as high as can be obtained conveniently without unduly complicating the design in order to eliminate unnecessary or premature blowing, but the fuse must not hold so long as to allow equipment or mains to



(C) (B) (A)

Fig. 1. Fuses for network transformers; at the right are 2 of the older copper links, and at the left the new link with fusible alloy

be damaged by overheating. A long time lag delays the clearing of primary faults when the network protector fails to open, but such cases are rare and the delay is not important. The fuse must have reasonably low losses in order to avoid adding to the temperature of the already hot compartment of the network protector.

The New Thermal Fuse

Because there was no fuse commercially available that had the desired characteristics, the Brooklyn Edison Company undertook to develop such a fuse and after some experimenting produced the fuse shown in figure 1 at *C* and in figure 2. A comparison of the characteristics of the various fuses is given in table I and the time-current curves of the fuses, together with the permissible loading curve of the transformer, are shown in figure 3. The time-current curve of the new fuse lies much closer to the permissible time-current loading curve of the transformer than either of the copper link fuses. The minimum blowing current of the new fuse is greatly reduced and the time required to blow on high current is from 10 to 20 times longer than that of the old fuse, which is a vast improvement in the right direction. The network protector and network mains have less thermal capacity than the transformer and might be damaged before the transformer on high currents, so that it is not considered desirable to increase the thermal capacity and delay the time of operation of the new fuse any further.

The time-current characteristic of the new fuse varies considerably with the initial temperature of the fuse. Since the fuses are located in the network-protector compartment which is mounted directly on the transformer tank, this initial temperature is influenced by the losses in the compartment and also by the transformer temperature. Under reduced loading, the lower temperature increases the minimum blowing current and the time of operation of the fuse, thus taking advantage of the greater ability of the transformer to withstand overloads when starting cold. The time-current curve in figure 3 for the new fuse assumes the network unit, to start from full-load temperature rise in summer which results in a minimum blowing current of about 165 per cent of rated transformer current. A fuse of lower rating would be in danger of operating on overloads resulting from outage of 2 or more adjacent transformers. However, overloads that are insufficient to blow the new fuse are unlikely to damage the transformer and associated equipment within one hour, which is considered sufficient time in which to relieve the condition.

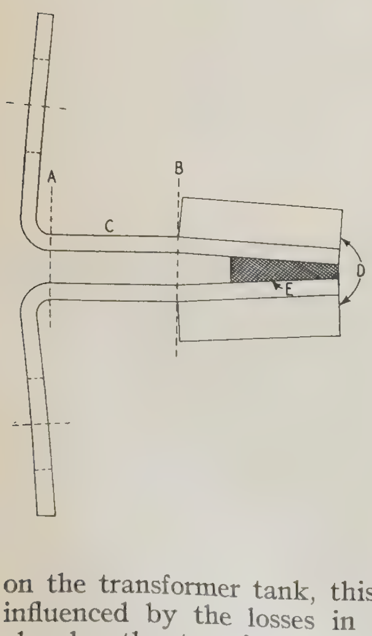


Fig. 2. Cross section of new type of fuse

A-B—Section in which most of heat is generated
C—Copper strap
D—Copper blocks
E—Alloy

The principle of design and operation is as follows: In order to reduce losses, the heat required to blow the fuse is reduced by adopting an alloy of low melting point as the fusible element. The time of operation is increased by adding thermal capacity in the form of copper blocks adjacent to the alloy slab. Most of the heat is generated in section *A-B* shown in figure 2, and a portion of the heat flows outward, heating the copper blocks and the alloy slab. The minimum blowing current is approximately proportional to the cross section of the copper in section *A-B*, and approximately inversely proportional to the length. The minimum blowing current may, therefore, be varied by changing the thickness of the copper strap, and the time required to blow on high currents may be varied by changing the thickness of the copper blocks which are riveted and sweated to the straps.

Table I—Comparison of Characteristics of Fuses for Use With 3-Phase 500-Kva 125/216-Volt Network Transformer

		New Type of Fuse	Former Types of Fuses	
			A	B
Approximate minimum blowing current, amperes	Summer	2,200	3,300	3,800
	Winter	2,800	3,300	3,800
Time at 15,000 amperes, seconds	Summer	7.5	0.4	0.6
	Winter	12.0	0.4	0.6
Loss per fuse at 1,333 amperes, watts		19	77	81

With this type of fuse, there is a critical limit of current above which the fuse will blow in the bend of the copper strap before the heat has time to flow into the alloy slab. In some of the first experimental fuses this point occurred at about 16,000 amperes, but it was raised above 20,000 amperes by lengthening and increasing the thickness of the copper strap in section *A-B* while maintaining constant resistance for the section.

The fusible alloy is a eutectic mixture of lead, tin, and cadmium (32 per cent lead, 50 per cent tin, and, 18 per cent cadmium by weight) which melts at 145.5 degrees centigrade. Although other mixtures may be used (such as 62 per cent tin and 38 per cent lead, which melts at 181 degrees centigrade), it is believed that the melting point of 145 degrees centigrade gives more uniform protection during the different seasons. The higher ambient temperature in summer causes the fuse to blow more quickly than in winter, but the transformer winding temperature is limited to about the same value in both seasons.

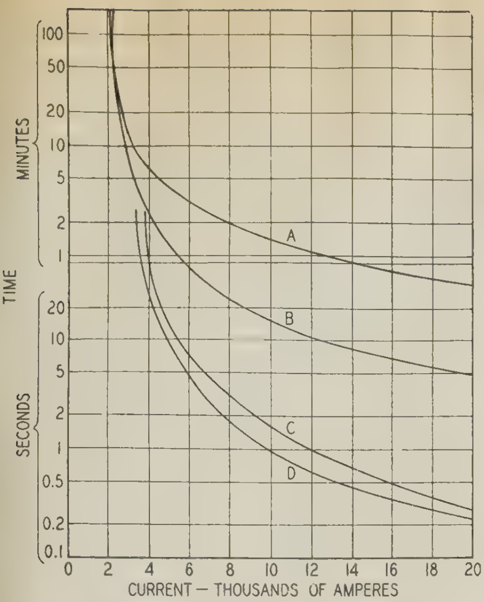


Fig. 3. Time-current curves

A—Permissible loading for 500-kva network transformer

B—New type of fuse

C—Type *B* fuse

D—Type *A* fuse

The thickness of the alloy slab must be sufficient to prevent any possibility of the copper straps touching together after the alloy is melted. To make doubly sure of this, in case the busses are poorly aligned, the mounting ends of the fuse are bent at a slight angle so that the alloy slab is under tension after mounting. Tensile tests have proved that the copper straps will bend readily when being mounted, without subjecting the alloy slab to excessive stress.

The shape of the alloy slab is merely for convenience in pouring and may be varied considerably in thickness and area without affecting the time-current curve. The fuse is usually refillable unless damaged by unusually high currents or by arcing. Test points on the time-current curve are very consistent and can be rechecked with almost exact agreement provided the ambient temperature is unchanged; however, a change in ambient temperature will vary the time-current curve considerably.

The fuse invariably blows at the upper junction between the alloy slab and the copper strap. Normally there is a small quantity of alloy melted out, but if the fuse is blown on heavy currents the arcing will cause additional melting. If any of the initial mounting tension still exists at the time of blowing, it reduces the amount of alloy melted to obtain the necessary clearance. Blowing the fuses on heavy currents in an enclosed compartment causes a grayish nonconducting dust to be deposited upon some parts of the network protector.

Field tests in which all 3 fuses were blown at 10,000 amperes in the enclosed compartment of a network protector, with normal recovery voltage, gave satisfactory results. For the past year or more these fuses have been used for new installations and replacements, and there are now about 250 in service. The fuses cleared satisfactorily in the only cases required, where a short circuit on a primary feeder was accompanied by failure of the network protector to function.

Lighting Improved in Industrial Plant

An improved lighting system recently was installed in the factory of the Crosley Radio Corporation, Cincinnati, Ohio, which provides an illumination intensity of about 25 foot-candles with a power consumption of approximately 3.6 watts per square foot of floor area. Views "before" and "after" installation are shown here.

In the new system the luminaires are hung 9 feet from the floor, and 150-watt inside-frosted lamps with silvered bowls are used; 200-watt lamps are used where fine inspection work is necessary. It is estimated that the entire cost of the installation will be paid for in 5 years by the savings it will effect over the former method of changing the illumination of the different departments every time a change was made in production plans and facilities.

Today's Trends in Lighting

Obviously it is impossible to prophesy accurately what will happen in any phase of human activity. In the field of lighting, however, it is fairly safe to make some predictions based upon the following hypothesis: Throughout the world there are certain organizations and establishments which are unusually progressive, which do things before the ideas involved have been accepted generally. A study, therefore, of what is being done in these outstanding examples gives an indication of what is likely to become general practice in the next several years. On this basis the author analyzes lighting methods in certain definite fields, such as stores, restaurants, industrial plants, and streets. He describes installations of new types of illuminants and new methods of applying the older forms.

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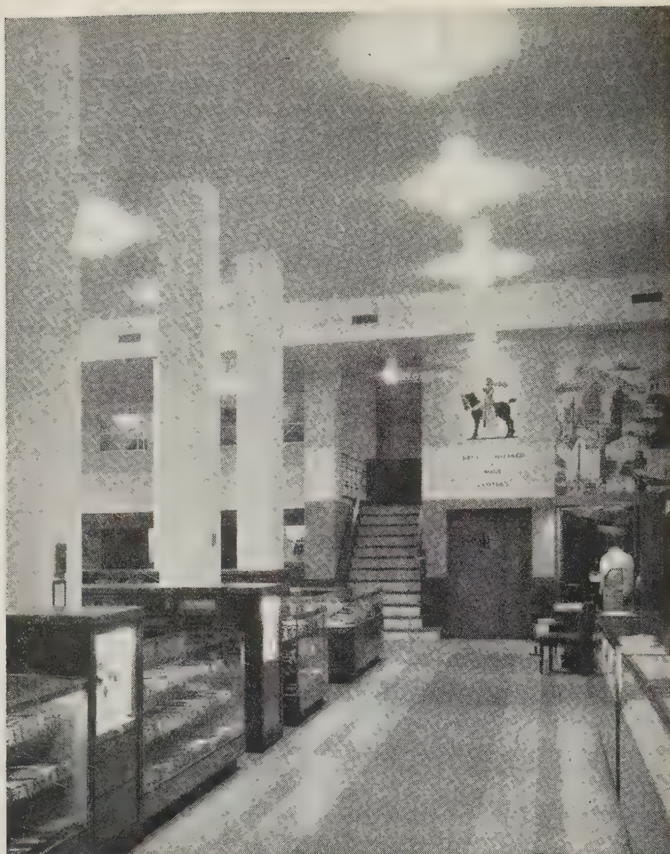


Night view of Wallach's clothing shop, Fifth Avenue, New York. Close ceiling boxes with prismatic refracting plates and 3 100-watt lamps each are used. Two lamps in each unit are controlled by photoelectric cells recessed into the column at the front of the store. Illumination level, 20 foot-candles

PROBABLY a half-million years elapsed before man developed simple pottery lamps and candles; then another 2,000 years before a variety of lighting tools became available. It was less than 30 years ago that the only practical electric lamps were powerful but cumbersome arc lamps, and inefficient low-candlepower carbon-filament incandescent lamps. The entire range of sizes of incandescent lamps was 2, 4, 8, 16, 32, and occasionally higher candlepower.

Now the arc lamp finds very little application for general interior lighting. It fills an important place, however, in projection work, photography, and other specialized fields.

Incandescent lamps in some 8,000 types are now supplied by manufacturers. For use on standard commercial circuits these range in size from 3 watts (2 candlepower) to 50,000 watts (more than 100,000 candlepower). Many constructions of filaments are made for different requirements and containers or bulbs vary in shape from tiny spheres to cylinders nearly a yard in length.

A paper based upon an oral presentation before the illumination group of the AIEE New York Section, January 14, 1936; recommended for publication by the AIEE technical program committee. Manuscript submitted February 13, 1936; released for publication April 2, 1936; brought up to date, September 1936.

The gaseous-conductor light source was really discovered by Geissler nearly 80 years ago, but it remained for Peter Cooper-Hewitt, D. McFarland Moore, Georges Claude, and others to make the basic idea practical. Through the use of various gases and colored glass tubing a wide range of color is now available. In basic design there are the high-voltage simple Geissler tubes with cold cathodes and a whole series of more-powerful lower-voltage lamps with hot cathodes. The types of tools which this illuminant provides are not as great in number as those embodying incandescent lamps, but their characteristics are much more varied.

During the past 2 years, radically new developments have occurred. Research laboratories have announced the development of so-called capillary mercury lamps where the light stream is about one millimeter in diameter and less than an inch long. Illuminating engineers are taking advantage of properties of fluorescent material and an entirely new field thus is being opened. Fluorescent gaseous-conductor tubes already are being used abroad

quite extensively and are gradually coming into use here. These are so unique that a brief description is not amiss.

The gaseous stream emits visible radiation (light) plus a certain amount of invisible radiation (ultraviolet). The glass tubing, in general, absorbs this ultraviolet radiation. If the inside of the tube, however, is coated with a substance which fluoresces under the action of the ultraviolet radiation, this process transforms the invisible radiation, normally absorbed, into light. The light generated in the gas stream tends to pass out through small openings in the fluorescent coating. Such a scheme takes advantage of something that would be lost ordinarily and makes possible especially high efficiencies.

Space does not permit more detailed discussion of new light sources themselves; these are treated rather fully in a report of the AIEE committee on production and application of light which appears elsewhere in this issue.[1] Light is the cause, illumination the effect. Light is generated to produce illumination. This particular paper deals principally with the application of light.

1. For numbered references see list at end of paper.

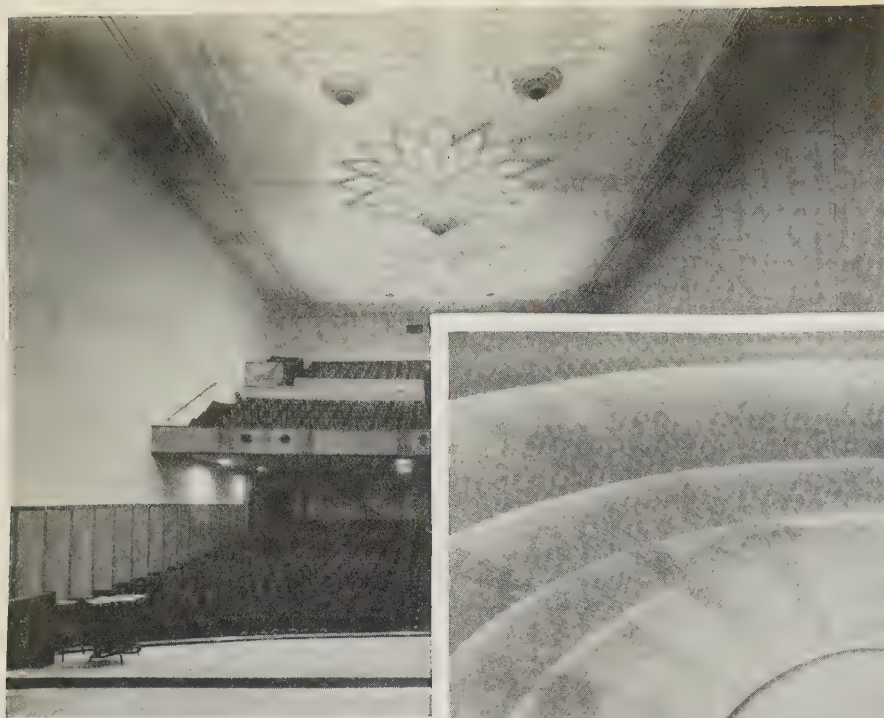
Store Lighting

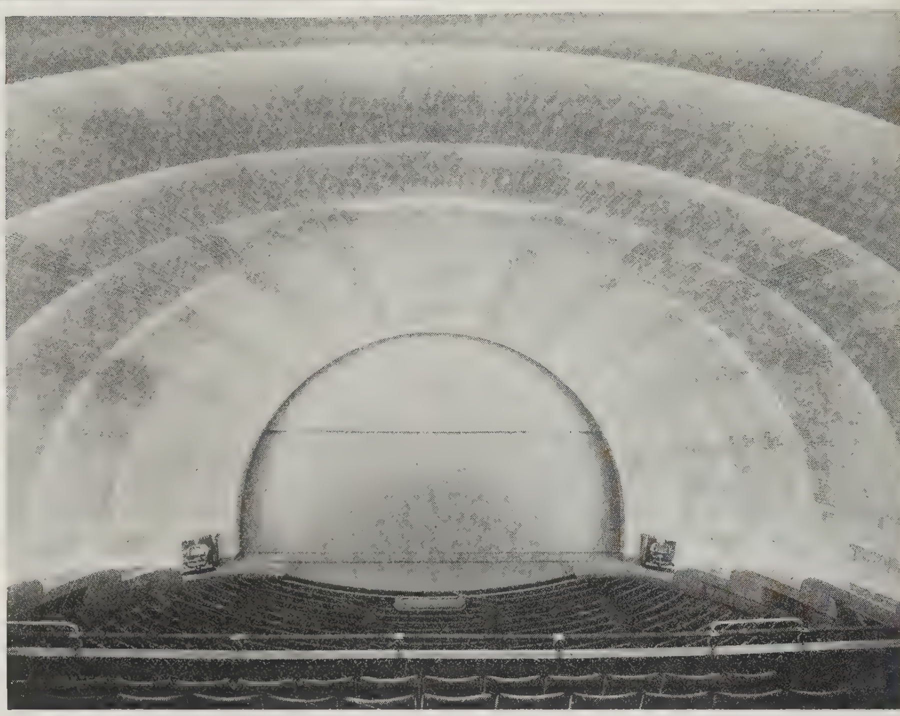
Since marked advances have been scored in recent years in store lighting, it seems desirable to begin with a somewhat detailed discussion of practice in this one particular field of illumination.

For many years it has been the custom to light a store by placing outlets on approximately 10-foot centers, 4 in each typical bay. These outlets served luminaires consisting of a canopy, chain, globe holder, and an opalescent diffusing enclosing globe. About the only variations were slight changes in the shape of the globe and the addition of minor ornamentation on the metal work or glassware. This scheme made the store appear bright and cheerful and all parts of the whole interior were more or less equally bright due to the diffuse character of the illumination. No special effort was made to concentrate illumination on the merchandise, and probably the eye was drawn more to the lighting units and the ceiling than to the things on display. There was no real attempt to control the light.

About 2 years ago a new movement was started to provide the maximum illumination on the mer-

Night view of the main floor of the store of S. H. Kress and Company, Fifth Avenue, New York. Through cast aluminum louvers of architectural design light from 500-watt incandescent lamps in mirrored glass reflectors is projected toward the merchandise. Large indirect luminaires give the effect of added ceiling height. At the center of each of these is a louvered direct projector. In the main body of the store the illumination level is of the order of 50 foot-candles and on the side counters it approaches 100 foot-candles





(Below) World's largest theater, Radio City Music Hall, is indirectly lighted in varying color. The hung ceiling consists of a series of 8 sections slightly inclined to each other. At the forward opening between the sections is placed the lighting equipment. Over 3,000 100- and 150-watt lamps are used

(Above) The decorations of the ceiling of the auditorium of the Juilliard School of Music in New York are merely projected shadows. Over each lamp a basket-like arrangement is used to produce the symmetric pattern

chandise and really direct the light to the proper areas. This is not an entirely easy matter and, if not done with proper skill and technique, may be most unpleasant. Fortunately, however, the results secured have been excellent, and the movement has expanded with the development and appreciation of the new technique.

Several schemes have been used which basically are more or less the same, differing only in detail. The method, as a whole, might be described as lighting through ceiling ports. In one system, concentrating reflectors are placed above the ceiling level and flush "egg-crate" or concentric louvers are used to prevent the light source from being visible save when one looks directly upward. Another scheme uses prismatic refracting plates to control the distribution and prevent glare. If conditions are proper, projector units with ornamental louvers can be applied.

For the average height of ceiling, outlets can be placed in the proper position relative to the counters so that these are lighted more brightly than the aisles. It generally has been found desirable to add a component of indirect light to prevent the ceiling from appearing too dark and to give an area of reasonably high brightness for its cheerful effect. Very often this is accomplished from equipment at the top of the side-wall cases.

Sometimes prismatic refracting plates are dropped slightly below ceiling level, thereby providing for a little flux distributed sidewise for ceiling illumination. Among the outstanding examples of this new approach to the store lighting question are the following: S. H. Kress Company, Fifth Avenue, New York; W. C. Fleck and Brothers, Jenkintown, Pa.; G. Fox and Company, Hartford, Conn.; Pauson and Company, San Francisco, Calif.; Wallach's, Fifth Avenue, New York; E. J. Hickey Company, Detroit, Mich.; Weber and Heilbroner, Fifth Avenue, New York; and numerous smaller shops.

This method of lighting through ports is by no means the only new development in store lighting. Every merchant seems to have realized that the old system of pendant diffusing units is a thing of the past. Most of the schemes of inbuilt and architectural lighting have been applied to stores. There have been some splendid examples of indirect illumination without the use of ceiling luminaires, as in Gimbel's department store, New York. Where pendant luminaires have been retained, these have been of novel, modern design.

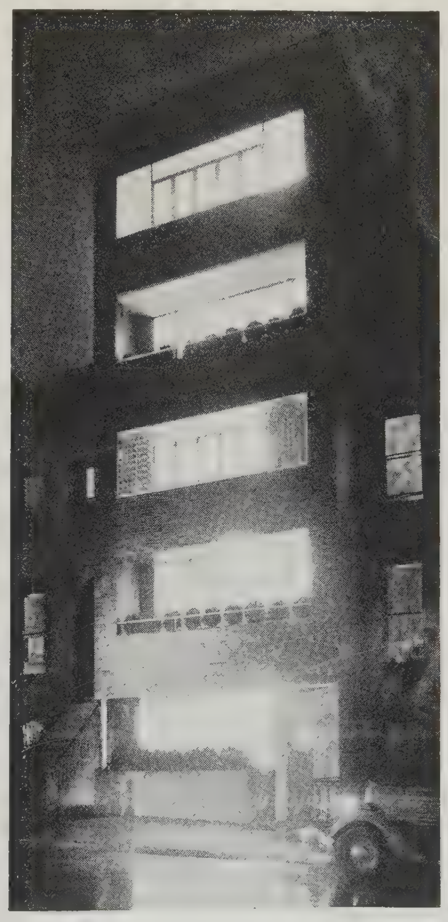
Merchants for many years have desired a whiter light than is given by the "mazda" lamp. Because of this desire, the enclosed arc lamp was retained in stores long after high-wattage tungsten-filament lamps became standard. Numerous expedients have

been used to obtain color modification. It has been found most practical to combine in one luminaire low-pressure mercury-vapor (Cooper-Hewitt) and incandescent lamps. The blue-green of the mercury tube supplements the predominant yellow of the incandescent lamp and by addition produces a splendid synthetic white light. This can be used for the display of merchandise with telling effect. This combination lighting is sufficiently correct as to color for illumination of merchandise which does not, in general, involve the most accurate color identification. There is no end to the possibilities in design of equipment using this combination lighting. Radically different forms are found in the showroom of the Chrysler Sales Corporation in Detroit; at John Wanamaker's store in Philadelphia; and in several of New York's Fifth Avenue fur shops.

Another practice which is most commendable is that of furnishing display emphasis by means of specific lighting. Much more attention is being paid to the illumination of wall and counter cases, and new and clever schemes are being used for obtaining the desired effect. Shelving of all sorts is being illuminated, and special local lighting is being used for displays on counters and tables. Merchants are beginning to appreciate the drawing power of light, for they are mounting on the ceilings of stores spot and floodlights shooting their beams toward particular areas, and special goods fall under the slogan of "spot-light sales." There are many new methods for illuminating mirrors. Floor mirrors for examining shoes have lighting as a component part; triplicate mirrors have inbuilt lighting at the sides, and millinery mirrors use the same system.

In the show window there has been a steady increase in illumination since tests have proved that more people are attracted by higher foot-candle values. As the power expended in the window is increased new problems are introduced by the accompanying temperatures. It is doubtful if much higher levels can be provided without some special means of disseminating the heat, such as absorbing the radiant heat at or near the source and then cooling the absorbing medium by some standard method.

In the tests on show windows it was shown that color lighting properly used has even greater drawing power than the highest levels of unmodified light. This does not mean merely flooding the window with primary colors and distorting the appearance of all objects. It means the utilization of delicate tints with spot and floodlight effects in contrasting colors superimposed. There is no doubt that the time will come when the display man will take his cue from the stage manager and light the show window like a miniature stage. This idea has been advocated for nearly 2 decades, but still the possibilities are not appreciated; it is deplorable that the advance has been so slow.



Night view of the exterior of a modern small apartment building. Glass bricks are used for a considerable portion of the wall area. By day the interior is effectively lighted, and by night the facade is especially striking

Luminous Building Exteriors

As one glances down a business street in a typical American community he certainly is not thrilled with the vista. Store fronts are far from attractive. An occasional modern note is flanked by ugly relics of the mid-Victorian era. If he possesses imagination he can visualize through the proper application of light this whole scene transformed into an attention-compelling radiant picture. There is literally no end to the combinations of light and decorative treatment that can be used to effect this rejuvenation. It is a relatively inexpensive matter to modernize a store front. Without changing the general outline of the facade, a progressive architect can submit to his client a dozen combinations of entrances, show windows, luminous areas, and restrained, effective advertising. There is no doubt that the time is near at hand when the antedated establishment will be forced to modernize through competition.

New structural materials are to be seen on every hand. Glass with its trans-illumination properties is coming more and more into use for this purpose. Hollow glass bricks and glass tile and blocks are becoming standardized, and one may find scattered instances of their use both here and abroad. A wall constructed of glass blocks is interesting by day and most striking by night.

Architectural Lighting

For centuries architects have given much thought to the appearance of buildings in the daytime. The profession has developed a technique that is superb. Until very recently the architect has not had at his disposal artificial light sources of sufficient variety and power to permit him to do really telling things. He permitted others to influence him toward inadequacy and tended to place emphasis on the decorative features of the equipment or its appearance in the daytime rather than the artistic merit of the entire illumination effect. In most cases, as far as general artificial lighting was concerned, his draftsman placed outlets on established centers, and when the

building was nearing completion various fixture manufacturers submitted designs and the best of these finally was selected. It was rare, indeed, that the architect himself designed the luminaires, and he gave but little thought to artificial light as a decorative medium and a component part of his conception. In spite of the preaching of a few forward looking lighting engineers, it remained for the modern movement in architecture, engendered by the Paris Exposition of 1925, really to awaken in the minds of the architects a new concept of the possibilities of applied light. This modern movement in lighting has passed through various stages. At first, radically severe lines predominated. Then as the whole modern trend took on a slightly more-classical aspect, lighting equipment followed.

Space does not permit a discussion of built-in lighting itself which is rapidly improving and advancing. With this scheme the luminaire is a component part of the structure and some truly lovely effects have been created in this manner. Numerous outstanding examples of such installations could be listed. In passing, one might mention the New School for Social Research and Radio City Music Hall where the light sources are literally in the ceiling itself and yet the lighting effect is all indirect; the auditorium of the Western Union Building, where indirect light emanates from the window sills; the lobby of the Chrysler Building; various sections of the Hotel New Yorker; the Earl Carroll Theater, now the French Casino; and the public spaces of the Empire State Building. (All these are in New York.)

With the development of new forms of light control devices the illuminating engineer is learning a new technique. He has ways and means of covering definite areas with sharply controlled light of any tint or brightness desired. In other words he can now put just the kind of flux he wishes on the areas he desires at the very time required. A splendid example of such a procedure is to be seen in the new Boardwalk Café at Jones Beach State Park, Long Island, N. Y.

Modern lighting, however, is not alone applicable to the modern building, for a true definition of modern lighting is that sort which permits a modern light source, such as the tungsten-filament lamp or the gaseous-conductor tube, to function effectively. By this definition an old chandelier adapted to electricity is not modern, neither is a round-bulb lamp on the end of a paper tube, the so-called candlestick motif. To make a truly modern luminaire requires more intelligence than just copying a past design. Imagination and a knowledge of the principles of the action of light must be brought into play. Through their use, however, there have been produced luminaires representative of Assyrian, Greek, Roman, Gothic, Renaissance, Georgian, and all the other decorative periods which are in perfect harmony with the spirit of the period and yet which are true twentieth-century products. Everyone who gives the matter careful thought must acknowledge that through this means the lighting of the future will advance. Period interiors will remain extant, but they will not be made uncomfortable or inadequately lighted merely because some decorator thinks that the only thing that can be done is to copy exactly what was used hundreds of years ago with radically different light sources.

Projected Light Decorations

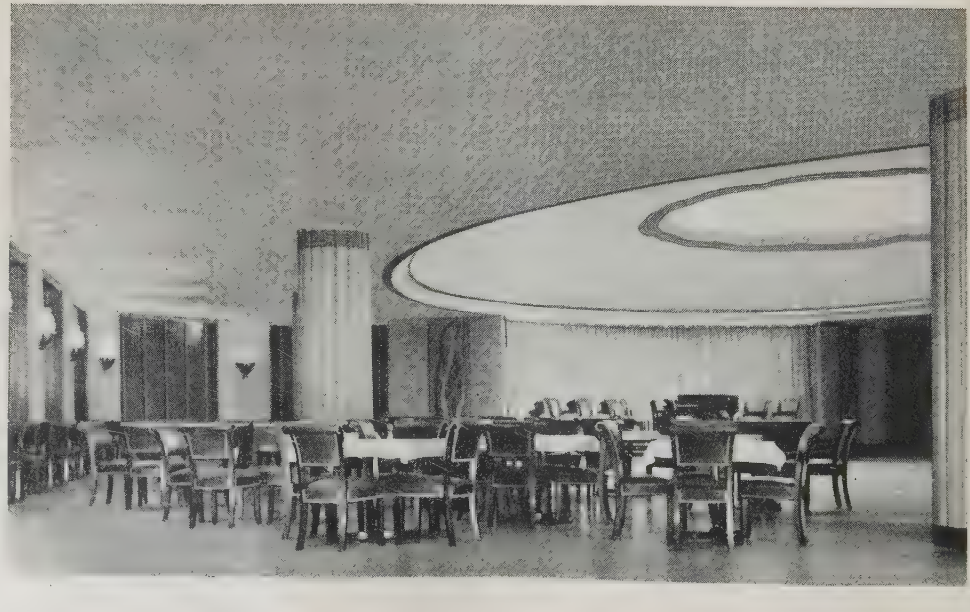
Light from a concentrated source radiates in straight lines. If a concentrated-filament lamp is placed in a container that reflects but little and a cover is put over the container on which there is a design in silhouette, in color, or a combination of both, this design will be projected in an enlarged form to any surface in the path of the light.

This principle has been used on the stage for years in the Linnebach lantern. It has been applied only recently, however, for general interior lighting. Its potentialities are so great that there is no doubt of the future development.

A whole series of small units can be placed in a cove and a colorful luminous frieze or border produced. Through the use of several sets of units on different circuits changing effects are at one's disposal. Such a scheme has been applied very effectively in Sweet's Persian Gardens, Oakland, Calif.

A single high-wattage lamp may be placed within

View of Boardwalk Cafe, Jones Beach, Long Island, N. Y. Tiny "down lights" illuminate the table area. The outer ceiling is given shadow patterns from indirect side-wall urns. The 2 shallow central domes can be painted at will with light of any color through the use of elliptical spot lamps of special design. Extremely uniform effects without any "spill" light are produced



a perforated cage-like arrangement and a whole room covered with a decorative pattern. This method was used at the Standard Oil exhibit, at the Century of Progress, Chicago. Here 2 10-kw lamps were the light sources.

A pendant indirect luminaire may be covered with an inverted basket-like device to produce a decorated ceiling through light and shadow. This arrangement provides the ceiling treatment in the auditorium of the Juilliard School of Music, New York. Inserts of colored glass can be an added refinement giving spots of brilliant color in addition to the basic design.

Indirect side-wall urns may be covered with a stencil and geometric or floral patterns projected on the wall. This scheme proved very effective in some of the pavilions of the Barcelona (Spain) exposition. This method of decoration is most inexpensive and has the added feature that changes can be made at minimum cost.

Luminescent Decorations

Within the last few years there have been developed rather comprehensive lines of varnishes and dyes which

(Top, right) The Cafe Le Triomphe on the Champs Elysees, Paris, France, gives a new touch to the modern treatment. A very pleasingly tinted illumination is produced by a combination of neon and fluorescent mercury tubes concealed in the ceiling coves

(Above) It is possible to combine tubular lamps into decorative patterns with telling effects. In one of the Longchamps (New York) restaurants straw-colored lamps are mounted in groups at the bottoms of air conditioning distributors

(Right) Luminescent paint is used on the side walls of the Club Trouville, San Francisco, Calif. When ultraviolet sources are turned on a brilliant, glowing picture results. A portion of each tablecloth is decorated with a fluorescent effect

(Left) The cocktail lounge at the Hotel Biltmore is treated in the empire style. Indirect luminaires are on low pedestals and provide adequate illumination. The luminous portion of these is based upon the characteristic empire vase motif

become luminous when exposed to ultraviolet radiation (often improperly termed black light). These colors are excited by the invisible radiation and transform this to radiation of longer wave lengths, violet, blue, green, yellow, orange, and red, depending on the chemical composition of the pigment. An interior may be decorated with these colors and the painted or dyed decorations may be invisible under ordinary artificial light, or may be of rather dull colors. When the light is turned off and a source without visible radiation but rich in ultraviolet radiation is turned on, objects painted with ordinary pigments become either invisible or rather dull and the luminous decorations, brilliantly colored. Some of the luminescent materials are fluorescent, that is, they glow as long as the exciting source is in operation; others are phosphorescent, continuing to glow in total darkness. Of course, the application of this feature is definitely limited to those places where quite low illumination will suffice, darkened theaters and restaurants, and possibly some out-of-door areas.

Incandescent lamps operating at high efficiency emit a certain amount of "near" ultraviolet radiation. If this radiation is passed through a special dark glass screen known as "red purple ultra," the visible radiation is absorbed and the invisible radiation transmitted. Similarly, flux from an arc lamp can be filtered. Probably the most practical source for illuminating luminous decorations is a mercury-vapor lamp of nickel-cobalt glass.

In application various objects in a room are treated with luminous paint. Most of the time the ordinary artificial light is employed, but at certain times the ultraviolet sources are brought into service and a complete transformation results. This scheme has been employed at a number of expositions and special shows, but recently some of the restaurants and night clubs have taken advantage of this spectacular illumination. A notable example is the Club Trouville, San Francisco; here the walls are painted with luminous scenes, the tablecloths are dyed with fluorescent decorations, and some of the glassware is of fluorescent material. Scattered about the room are numerous mercury-vapor lamps with the black glass tubes, and when these are used a startling change takes place.

In some instances rooms have had the ceilings studded with fluorescent and phosphorescent stars. Ultraviolet sources are used in indirect luminaires, and when the "mazda" lamps are turned off a purple glow fills the space with the stars shining brightly. This new field has not yet been fully investigated.

A good example of a truly modern luminaire which is strictly classical in design and feeling. Two 75-watt lamps provide indirect illumination and one 40-watt tubular lamp illuminates the metal work and the crystal sprays

Use of Tubular Light Sources

With the modern movement in architecture and the advent of new forms of gaseous-conductor lamps, greater interest has been shown in extended rather than concentrated light sources. This has brought about the development of many new types of incandescent lamps. It was not so long ago that the only tubular filament lamp was the short, so-called "bunghole" lamp. New construction methods made possible a 40-watt lamp, 12 inches long, and later 75- and 150-watt lamps of the same length. The culmination of this series was a 100-watt lamp 34 inches long. With these lamps the base and socket made a noticeable break in the line of light. Recently, however, there has appeared a line of double-ended tubular lamps which when used end-to-end give the effect of a practically continuous light source. In America these are known as "lumiline" lamps and there are available commercially a 40-watt unit 12 inches long and 30- and 60-watt lamps 18 inches long. In Europe curved and angular shapes are also on the market, but in general these are so relatively high in price as to make their use limited from economic considerations. Such lamps are used exposed to form desired decorative patterns, and they open up a new field in the design of the luminaire itself.

Public Buildings

The modern public building is being provided with architectural lighting in the true sense of the word, but there are still a few ideas that have not yet met general acceptance.

In the church, light control should be more prevalent. It is desirable to have the main auditorium on one circuit, the sanctuary lights on another circuit, and a soft-edge spotlight for the pastor or priest on a third circuit. Each of these should be controlled by dimmers, and with the proper manipulation of these, the congregation's attention is focused on the important part of the service.

In the art gallery, the most progressive directors are showing art objects and paintings in their natural settings. Gothic art may be displayed in a reproduction of a thirteenth century chapel; Renaissance works in a room transplanted from a French chateau; English pieces in a Georgian drawing room; and so on. Modern lighting makes it possible to fur-

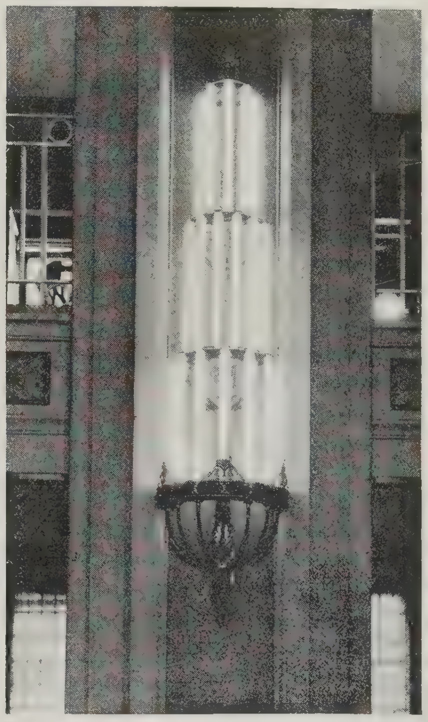
nish adequate artificial illumination for any of these settings without the casual observer being conscious of the slightest incongruous touch. In the large picture gallery the skillful designer can furnish artificial light of such distribution and quality that the most experienced technican finds it difficult to tell whether natural lighting, artificial lighting, or a combination of both is being used. There is no longer any excuse for making the elaborate attempts to provide natural lighting for interior rooms. Museums need not be one-story buildings with skylights overhead. The new Kansas City (Mo.) Art Museum is a beautiful illustration of this fact.

The American Museum of Natural History in New York also has undergone a striking change. A few decades ago case after case of stuffed birds and animals were arranged in soldier-like precise rows, each specimen duly labeled with its proper genus. The new African wing of this museum has all its groups placed in the most naturalistic settings. The naturalist, the taxidermist, the scene painter, and the lighting man all co-operated in producing the final result. The management here realized that it had something to learn from the theater, and month after month one of the leading stage-lighting technicians worked with the museum staff. All the tricks of the stage, spot and floodlights, and color effects have been brought into play.

In the bank building much more efficient operation has been made possible through a greater appreciation of the potentialities of lighting. No longer are bank luminaires chosen merely because they are pleasing works of bronze or wrought iron, but are selected to do a definite job by putting light where it is needed and at the same time be beautiful things both lighted and unlighted.

Court houses, unfortunately, are rather far behind other classes of structures, and all too often the dim, religious atmosphere prevails or the Stygian blackness is punctuated by glaring, exposed lamps. Light and justice should go hand in hand. It is rare that special lighting is provided for the witness stand so that the expression of the individual testifying can be observed by the jury. The advantage of this practice is obvious. Generally speaking, the justices do not have proper illumination for the examination of documents. There are many pieces of evidence that should be scrutinized most carefully, and common sense says that every court room should have some place where a high level of artificial daylight is provided.

One might continue such an analysis for many other types of structures, but these few examples give an indication of the trend of thought of the illuminating engineer.



The new "lumiline" lamp opens up a remarkable field to the fixture designer. This luminaire in the Newark Athletic Club building illustrates just one approach

Lighting for Seeing

For many years illuminating engineers have known that improved seeing conditions resulted when higher levels of illumination were provided without the counteracting effect of glare. Data to prove this were rather meager; but it seemed most logical because human eyes have been developed under countless centuries of work under the hundreds of foot-candles which prevail out-of-doors. In the last few years there has been carried on much research on this whole question of the "science of seeing." Laboratory technicians have made measurements of the human reactions, ability to see, expenditure of nervous energy, and resultant fatigue under varying lighting conditions. The findings have brought out new indications of the human value of higher and better illumination than could be justified from the bare economic standpoint, for example in increased production, and speed of work. This new approach is having remarkable influence on practice in those places where the eye is called on to do the more-exacting tasks. As a result of nation-wide publicity and education, millions of homes are better illuminated than they were a year or 2 ago. Appreciation of the advantages of better illumination have spread to the office, school, and industrial plant.

Residence Lighting

The conservative side of one's nature tends to be particularly strong in the home. We see on every hand stores, office buildings, banks, and other public structures in the modern spirit, yet in spite of innumerable splendid designs for modern homes extremely few are being built. It is safe to assume that the home will be one of the last places to adopt truly modern lighting ideas, yet it can be prophesied that eventually the things illuminating engineers are talking and dreaming of today will come into general practice.

At the beginning of the century the city house was lighted by gas chandeliers and brackets with an occasional table lamp. The country home had hanging kerosene lamps and kerosene table lamps. Electricity had not come into very general use. When electric service became more common it was standard practice to transform gas fixtures into com-

bination units by the expedient of adding sockets and wiring. The carbon lamp of those days was not of high intrinsic brightness and the practice was not seriously objectionable.

Unfortunately, the lighting equipment industry had very little vision, and with the advent of the much-more-powerful and brighter tungsten lamp continued to make luminairies of the same general designs. A few illuminating engineers constantly reiterated that this practice would lead to the death of the industry. They pointed out that new methods of utilizing light were essential and that the public would react against glare, but all this was of little avail. As a result, the public did just what was predicted and began to use portable lamps or localized rather than general illumination in every possible point around the home. This was unfortunate, indeed, for the new, more-efficient light sources made adequate general illumination possible at reasonable cost. It was perfectly ridiculous to try to light a living room for a general party or a bridge party with table and floor lamps giving small pools of light here and there. In those homes already constructed where it would be difficult to modernize the lighting without radical changes, the indirect types of table and floor lamps offer a solution of the problem.

There is no doubt that the home of the future will incorporate lighting arrangements such as here pictured. Behind the bed is a semicircular niche. Lamps are concealed by a free standing column which serves as a reflector. The room is lighted indirectly from this wall niche. A soft diffused light of varying quantity and color can be obtained at will

The growing appreciation of the relation of light to vision mentioned hereinbefore has made the public really desirous of having adequate illumination at certain points for utility. The "I.E.S. study lamp" is one simple means of obtaining this, and the extent of the need is indicated by the fact that more than $1^1/_2$ million such lamps have been sold and are no doubt in use.

Whatever present practice may be, there is no question in the author's mind that eventually inbuilt lighting will be part of the construction of the home of the future. There will be light boxes at the sides of the windows; by day these will be hidden by hangings, and at night controlled light will flood the room from natural directions. Another scheme will employ boxes at the top of the window with refracting plates to distribute the light from lamps within. There will be luminous cornices, and niches will be built in the walls for artificial lighting. The old-style wall unit will be replaced by indirect and semi-indirect types. Artificial skylights will be used under certain conditions, and so on through a whole series of combinations and methods.

Mention has been made elsewhere of the use of glass as a construction material. Already there is in Paris an experimental house with one entire wall of glass blocks, lighted entirely from out-of-doors.

Certain decorative periods demand luminaires of their own particular style. Even these can be modern without glare. The crystal luminaire, for instance, can have incorporated in its structure small, indirect reflectors. Light passing through the crystal gives the necessary sparkle and yet the principal light is from concealed sources. A truly clever designer can make something fit any period and yet have it meet the approval of the most discriminating lighting man.

Industrial Lighting

The new high efficiency light sources, namely, the high-intensity mercury and the sodium lamps, make it possible to obtain higher levels of general illumination without increased operating costs. The mercury lamp gradually is meeting public acceptance in this country, but the sodium lamp, because of its monochromatic-color effect, has not yet been applied to any notable degree by American industry. Abroad, because of economic conditions, including less-efficient incandescent lighting, its acceptance is somewhat more general. It is believed that eventually considerable sodium lighting will be seen in industry. This will be confined to plants where color is of no consequence. It is not logical to expect that a device which gives 50 to 60 lumens per watt can remain neglected for a long period in spite of certain control disadvantages.

Recent investigations of the relation of lighting to seeing have indicated that far higher levels of illumination are desirable and necessary where very

fine detail is to be observed with speed and comfort. It is not feasible to illuminate the entire floor space to levels necessary at the work point. Old-style purely local lighting has passed, for there is too much contrast between the lighted area and the surroundings. The more progressive plants are using "general lighting plus." Here a moderate level of general illumination, 10 to 15 foot-candles, is provided throughout the room, and special means are used to bring the illumination of small areas to many times this value. Sometimes the conventional well-shaded drop light is installed; in other cases, to get the lighting unit out of the way of the operator, concentrating projectors are placed at a distance. Where the areas demanding good lighting are large, as, for instance, the side of an automobile that is being painted, it is not at all infrequent to note installations of 50 foot-candles and upward of controlled general lighting. There is a growing appreciation of what light can do in aiding efficient production. Frequently high-intensity mercury and incandescent lamps are combined to provide a better color quality.

There is still much to be learned regarding the best methods of lighting various industrial processes and right now the committee on industrial and school lighting of the Illuminating Engineering Society has several subcommittees making an intensive study of specific problems. Several reports on different industries have already been published.

General Lighting With Gaseous-Conductor Sources

For many years the incandescent lamp has been supreme as a light source for all ordinary purposes. Its color of light is pleasing and generally acceptable. While it is not a pure white suitable for accurate color identification, it does not distort color appearance seriously. It is efficient, compact, inexpensive, and simple to install and operate. It requires no auxiliary apparatus. It can be screwed into a standard socket connected directly across the supply voltage. It can be burned in any position. It is safe and practically foolproof. By changing the current through the use of a dimmer its light output can be varied at will. All colors are present in its continuous spectrum and colored flux can be obtained through the use of proper filters. Summing up, it has practically all the properties one would set forth if he were writing specifications for an ideal source.

In the last few years there has been a tremendous revival of interest in gaseous-conductor light sources. This has been brought about through the discovery and use of new gases and through the invention of more efficient types of lamps.

Gaseous-conductor light sources are inherently arc-discharge lamps, and it is characteristic of the arc to require some sort of ballast or control device to prevent the arc from "running away with itself" on constant potential. In other words, none of the gaseous-conductor light sources can be applied directly across the line, but must always have some sort of an auxiliary. Generally speaking, it cannot be screwed into the ordinary socket. True, by special construction, the necessary auxiliary devices may be actually incorporated in some types of lamps, making complete units, as in the case of the small negative glow lamp which has a resistance unit concealed in the base. Also, it is possible to place an incandescent filament in series with the high-intensity mercury lamp to act as a ballast, and to mount both in the same bulb. These are the exceptions, however, rather than general practice.

Gaseous-conductor light sources, by and large, emit colored flux, the color depending on the gas. Mercury has a blue-green line spectrum, neon orange-red, helium pinkish-white, argon purple, sodium yellow, and so on. Only one gas, carbon dioxide, gives a pure-white light, and the luminous

In this modern room, indirect lighting is furnished by one entire side wall. Behind a false beam, which acts as a valance, are placed tubular lamps. Similar units are used behind the vertical member at the left. Here the light sources are concealed from view by a new synthetic material, called "catalin," in the form of rods. In the mirror may be noted a reflection of a window with the glass curtains drawn. These are lighted from the top and bottom and give another low-brightness, natural source

efficiency of this is very low. Colored light falling on colored objects causes a distortion of appearance. Under monochromatic yellow sodium light, for instance, all other colors appear as black or shades of gray. Under mercury light one's lips appear black because of the lack of red in the spectrum.

Gaseous-conductor light sources, therefore, cannot be used in their simple forms for general interior illumination where color effects are important. Some of the lamps of this class, however, sodium and mercury particularly, are inherently so efficient that they find considerable application in industrial plants and spaces where color is relatively unimportant, in spite of their somewhat-more-complicated operation.

A high-intensity mercury lamp produces light at 40 lumens per watt and is a new tool for illuminating industrial plants to high levels at low operating costs

The big field for gaseous-conductor lighting is found when different sources are combined. It is possible to add the red of the neon to the blue-green of the mercury, and thereby obtain synthetically an approximate white. This scheme has been advocated, but has never found wide acceptance in America. The net efficiency of the combination is not above that of incandescent lighting, and the color is not novel enough to warrant the additional cost of installation and complications in control. In France a considerable amount of such combination lighting has been installed, using the fluorescent tubes mentioned elsewhere and employing high-voltage tubing. By combining this with the architectural construction some outstanding installations have resulted.

It is the author's opinion that the real field for gaseous-conductor light sources is in decorative interiors where color effects are desired. It has been mentioned that any color of light can be obtained from the incandescent lamp, but this is always through absorption methods. Even if the initial efficiency of unmodified light is in the neighborhood of 20 lumens per watt, red light is obtained at about 2 lumens per watt, green at about 3, and blue at a small fraction of a lumen per watt. It seems logical, therefore, to take advantage of the inherently high efficiency of gaseous-conductor sources as producers of colored flux. With neon lamps red light can be produced at approximately 14 lumens per watt; the mercury lamp can be made with yellow tubing, giving green light at approximately 7 lumens per watt, or with blue tubing giving blue light at approximately 8 lumens per watt.

If these 3 primary colors be combined, a synthetic white light results. The combination may be made in several fashions for decorative effects. For instance, in direct lighting 3 sets of tubes can be combined in a single unit. The fixture itself will be brilliantly colorful and the shadow effects produced most striking. Since each light source is separated by a small distance, fringed colored shadows result. Under suitable conditions these have life and charm. A slightly diffusing glass ceiling may be made into a mosaic of color by placing lamps above in a predetermined manner and similar effects are secured. These light sources may be used for indirect illumination. A trough may extend the length of the room. The ceiling will be brilliantly colored, the resultant illumination will be pleasing and not objectionable as is the case when colored light of one variety alone is used. Such a scheme is used in the House of Magic Conference Room in the General Electric Building, New York. A cove may be built around the room and red, green, and blue sources used in rotation sending shafts of colored flux across the ceiling. Small objects in low relief on the ceiling will cast most-intriguing complementary-colored shadows. Space does not permit a complete analysis of the potentialities of this new method of illumination. One's imagination can conceive dozens of possible combinations. With hot-cathode tubes such a volume of colored flux is produced as to give the maximum life to the color at reasonable expenditure for wattage.

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Progress in the Production and Application of Light

A review of progress in illumination during the past 4 years has been prepared by the AIEE committee on production and application of light,* and is presented here. This report deals primarily with new types and forms of light sources and improvements in old ones. Some examples of modern applications of these new light sources are discussed in 2 other papers in this issue: "Today's Trends in Lighting," pages 1100–10; and "Electrical Features of the Texas Centennial Central Exposition," pages 1060–74.

THE LAST published report of the AIEE committee on production and application of light appears in the June 1932 issue of ELECTRICAL ENGINEERING. As a matter of record, it seems desirable to review developments since that date. The 1935–36 committee has attempted, therefore, to set forth on the following pages a rather brief summary of what has transpired in the lighting field during the past 4 years. An attempt has been made to follow the same general outline used in previous committee reports and to treat related subjects in order. There are, no doubt, many errors of omission, for lighting is the branch of electrical engineering that probably undergoes the most rapid changes. If one follows the technical and trade press he may note each month some reference to new types and forms of light sources and novel applications of artificial light. It is impossible, therefore, to make a thoroughly complete record of all the changes that have taken place during the period under consideration; those interested are referred to publications devoted especially to lighting, particularly the *Transactions* of the Illuminating Engineering Society.

During the period of the depression there was evidently a slight reduction in the use of artificial light, for records indicate that the sale of incandescent lamps decreased during certain years. This figure is an excellent index of the use of electricity for lighting. During the year 1935, however, it is estimated that 707 million incandescent lamps were sold, of which 50 per cent were so-called large lamps and 42 per cent miniature lamps. This was a new high record and should indicate considerable revival in general business.

New Incandescent Lamps

Lamps for Photography. During the past 4 years the original "photoflash" and "photoflood" lamps have been supplemented by additional sizes. The widespread acceptance of the initial lamps of these types led to extensions of the lines to provide flexibility for all types of photographic service. The success of both types of lamps has been outstanding —the "photoflash" for newspaper and color photography, and the "photoflood" for amateur motion pictures in black and white and in color.

The first lamp is known as "photoflood No. 1"; it consumes 250 watts, has a life of 2 hours at 115 volts and emits 9,000 lumens of relatively high actinic value. The next size to be developed is known as "photoflood No. 4"—1,000 watts, 10-hour life, 35,000 lumens. There has just been listed a new size known as "photoflood No. 2"—500 watts, 6-hour life, approximately 17,000 lumens.

The "movieflood" lamp—2,000 watts, 66,000 lumens, 15-hour life at 115 volts—has been made available for professional motion-picture photography in color. There has been developed a special glass filter which, when employed with these high-efficiency lamps, gives a spectral quality ideally suited to the requirements of the so-called "technicolor" process.

"Photoflash" lamps have a bulb loosely filled with very thin sheets of aluminum foil in an atmosphere of oxygen, together with a suitable igniter. They provide a powerful, silent flash and are now available in 3 sizes for use under varying conditions: No. 10, which emits approximately 23,000 lumen seconds; No. 20, 45,000 lumen seconds; and No. 75, 180,000 lumen seconds.

"Lumiline" Lamps. While tubular lamps having contacts at both ends have been in use in Europe for a number of years, they have been expensive to make and when used end-to-end showed considerable unlighted spaces between lamps. A new lamp was designed which overcomes these limitations so that a practically continuous line of light can be produced.

The so-called "lumiline" lamp is a practical tubular lamp with a contact at each end. It incorporates an entirely new technique of sealing a metal contact directly to the end of a glass tube without the use of basing cement, and a special chrome-iron contact disk takes the place of the conventional base. A single coiled filament is drawn out into a continuous line from one end-contact cap to the other. A channel backbone inside the bulb carries the filament along the tube, the filament being anchored by wire filament supports attached to the channel backbone and spaced approximately 2 inches a part.

"Lumiline" lamps are made in lengths of approximately 12 and 18 inches. The 110-to-120-volt lamps are made in 30- and 60-watt sizes in the 18-inch length; the 40-watt lamp is made in the 12-inch

A report prepared by the AIEE committee on the production and application of light, in accordance with the provisions of Section 85 of the AIEE by-laws; recommended for publication by the AIEE technical program committee. Manuscript submitted July 7, 1936; released for publication September 14, 1936.

* Personnel of AIEE committee on production and application of light—1935–36: A. L. Powell, *chairman;* D. W. Atwater, J. W. Barker, Robin Beach, W. T. Blackwell, H. B. Dates, E. E. Dorting, C. L. Dows, C. W. Franklin, A. M. Hageman, L. A. Hawkins, J. T. Holmes, C. R. Jones, W. C. Kalb, H. E. Mahan, R. D. Mailey, and P. S. Millar.

length. In addition to being made in the clear and inside-frost finish, these lamps are made in a variety of pastel colors.

Three-Light Lamps. It is often desired to obtain several levels of illumination from a given lamp without the use of an auxiliary control or dimming device. For this need there have been developed lamps of several sizes with 2 filaments which may be operated independently or together. These lamps have mogul screw bases with 2 bottom contacts, the center a button and the outer a ring. Obviously, a special 3-light socket is required. Such lamps are available in the following sizes: 50–100–150 watts; 150–200–350 watts; 200–300–500 watts; 400–600–1,000 watts for general lighting; and 100–200–300 watts for base-down burning in indirect luminaires.

Lamp for Indirect Portable Luminaires. In addition to the first and last 3-light lamps mentioned, there has been introduced for use in indirect portable luminaires a 250-watt lamp with a compact round bulb of short light-center length. This permits the design of accessories of more pleasing proportions than could be made for the standard lamps. It is recognized that this service requires an efficient lamp even at the expense of life. This 250-watt lamp has a rated life of 500 hours and gives nearly as much light as the normal 300-watt 1,000-hour lamp.

Projection Lamps. There is a constant demand for more-concentrated, more-brilliant light sources for projection work, and manufacturers strive to produce the most effective lamps for this service. One development, in particular, has been of importance—the use of the coiled coil filament. Incidental to this development are new methods of treating the filaments which prevent them from warping and short-circuiting in service.

Another innovation in projection lamps is the so-called biplane filament wherein one set of coils is placed in front of another set and offset laterally. This arrangement tends to produce the effect of a solid-square source.

As a result of these changes, an attempt has been made to standardize a definite line of projection lamps for stereopticon and motion picture service in sizes from 50 to 1,500 watts for operation on standard line voltage.

Bipost-Base Lamps. For many years practically every incandescent lamp was of the same type of construction with the filament supported by some means from a glass stem. With the development of new materials and new techniques of manufacture it has been found possible to support the filament from metal rods or their equivalent, rigidly connected to heavy prongs which serve as contacts to the electric circuit. The bulb, in turn, is supported from this metal structure. This construction has many advantages because strong metal is substituted for relatively fragile glass as a means of mounting heavy filaments. The construction also permits accuracy of filament position limited only by metal working tolerances. The mogul bipost base has been standardized for the 5,000-watt and certain 3,000-, 2,000-, 1,500-, and 1,000-watt concentrated-filament lamps for floodlights, spotlights, and projectors. It is possible to burn bipost-base lamps of proper design base-up, which was out of the question with old-style concentrated-filament lamps.

Within the last few weeks there has been announced a smaller size or medium bipost base which has been applied to a 1,000-watt lamp in a tubular bulb 3 inches in diameter for general lighting service, and a special 4,000-lumen street series lamp.

The mogul bipost lamp requires a clamping type of socket, and the medium bipost lamp uses a new type of porcelain socket in which the lamp is inserted, then given a slight clockwise twist which locks it in place.

Change in Rated Life of 75-, 100-, 150-Watt Lamps. Investigation and computation showed that most lamps of these sizes operated under conditions such that a life shorter than the standard 1,000 hours would produce light at lower cost. Accordingly, the rated lives of these lamps recently were changed to 750 hours in order that the user might obtain his light at a more efficient point of operation.

Multiple Christmas Tree Lamps. Everyone has experienced annoyance with series Christmas tree strings of lamps. Until recently, however, lamps for multiple operation on 115 volts were too great in physical size for the best appearance. Now several standard styles of lamps are available for this service with surprisingly small bulbs and candelabra bases, consuming approximately 7 watts each.

Flashlight Lamps. During the period under consideration, largest and smallest types of flashlights were developed. The first is a 10-cell unit employing an 11.8-volt 0.5-ampere gas-filled lamp and producing a beam of approximately 20,000 candlepower. The small one is only 3 inches in length and $^1/_2$ inch in diameter. This uses a bulb about the size of a kernel of corn and requires but a single small cell (1.2 volts, 0.22 ampere). The upper part of the bulb is a double convex lens which concentrates the light into a rather brilliant narrow beam.

Low-Wattage Lamps for Standard Lighting Practice. The wattage or current taken by a lamp is, of course, dependent on its resistance, and this, in turn, on the diameter of filament. There is a limit to the size to which tungsten wire can be drawn by ordinary methods, namely, a size which made into a lamp will consume about 6 watts. If this wire, however, be uniformly etched or eaten away to smaller diameter lower-wattage lamps can be made. A line of 3- and 6-watt lamps in different bulb sizes is now available.

Base and Socket Standardization

The International Electrotechnical Commission, meeting in Brussels, Belgium, in June 1935, approved a number of standards that had been under discussion for several years. These included the acceptance of dimensions of European and American medium-screw and mogul-screw bases and their corresponding sockets. The American bases and sockets differ enough from the European so that they are not fully interchangeable. The objective ideal was retained informally as a practical compromise to be substituted for the American and European screw standards if and when conditions should permit.

During the past 4 years there has been an extensive development of gaseous conduction lamps, and the near future doubtless will see a comparable intensive development of them. Practically all these new lamps have been made possible by using some form of oxide-coated electrode and new glasses chemically resistant to the vapors or gases used and having characteristics that will enable them to withstand high temperature.

Three high-efficiency, so-called high-intensity, mercury-arc lamps have been developed. The 400-watt unit, 13 inches long and 2 inches in diameter, with a standard mogul base, has an actual light source about 6 inches long and about $1^1/_4$ inches in diameter. The lamp is rated for a 2,000 hour life with an initial efficiency of 40 lumens per watt in the arc itself. It can be operated from an a-c source by the use of a reactive transformer giving an over-all power factor of 0.65 or 0.95, depending upon whether or not correcting capacitors are used.

A similar 250-watt unit 8 inches long and $1^1/_8$ inches in diameter, with a standard medium screw base, has an actual light source about 4 inches long and 1 inch in diameter. The lamp is rated for a 2,000 hour life with an initial efficiency of 30 lumens per watt in the arc itself. Its electrical characteristics are similar to those of the 400-watt unit.

An 85-watt unit $5^1/_2$ inches long and 1 inch in diameter, with a standard medium screw base, has an actual light source about $^1/_2$ inch long and 1.5 millimeters in diameter. The lamp is being given a tentative life rating of 500 hours with an initial efficiency of 35 lumens per watt in the arc itself. The 85-watt lamp, sometimes called a capillary lamp, differs most definitely from the other lamp in details of construction and high intrinsic brilliancy.

By placing a small quartz-glass lamp, similar to the 85-watt unit, in a high-velocity stream of water, its wattage may be increased about sevenfold and an even greater increase in intrinsic brilliancy obtained. Lamps of this type are well along in development and may soon be available even in ratings of several kilowatts.

The 400- and 250-watt units already have found extensive application in industrial lighting use either in standard or slightly modified fixtures of the type long in use with incandescent lamps, or sometimes in combination with incandescent lamps. It is anticipated that the 85-watt unit will find a similar application where smaller amounts of light of the unique quality characteristic of a mercury arc is needed, and where so small a unit can be used to advantage in combination with incandescent lamps in built-in and so-called architectural lighting. The water-cooled lamp, the brightness of which is comparable with that of the largest carbon arcs, seems to be very adaptable to certain types of projection work with either condensers or lenses. All these lamps require reactive transformers.

Two sodium lamps have been perfected rather specifically for highway lighting use. The 10,000-lumen 180-watt lamp is $16^1/_2$ inches long and 4 inches in diameter, and has an actual light source about 9 inches long and 3 inches in diameter when enclosed in its insulating glass jacket. It is rated for a life of 2,000 hours with an initial efficiency of 56 lumens per watt in the arc itself.

The 6,000-lumen 140-watt lamp, is 14 inches long and $3^1/_2$ inches in diameter, and has an actual light source 7 inches long and $2^1/_2$ inches in diameter when enclosed in its insulating glass jacket. The lamp is rated for a life of 2,000 hours with an initial efficiency of 46 lumens per watt in the arc itself.

Both of these sodium lamps are designed for relatively low-voltage high-current (6.6 amperes) series operation on standard street lighting circuits. For this special use they are fitted with radio type prong bases.

For special applications, a variety of so-called hot-cathode lamps has been developed. These are generally mercury-vapor or neon low-voltage lamps operating on the Cooper-Hewitt rectifier principle through the use of a single oxide-coated cathode and 2 anodes. The advantage of this type of operation is that a practically nonflickering light source is obtained. Lamps of this type vary in light-source dimensions, being generally about one inch in diameter and from 10 to 60 inches in length. These lamps have efficiencies of the order of those of incandescent lamps of comparable wattage ratings, the over-all efficiency of the neon lamp being about 10 lumens per watt, including losses in the operating devices, and that of the mercury lamps about 15 lumens per watt, including losses in the auxiliary devices; both ratings are for bare lamps without reflectors or diffusers. These hot-cathode lamps already have found applications in tower lighting, in beacon lighting, in places where the distinctive color of the neon lamps is of value, and where the more certain starting in cold weather characteristic of the hot-cathode mercury lamps is a necessity.

A novel line of very-low-wattage so-called negative-glow lamps has been developed. These units use neon, argon, or nitrogen gases depending upon the effect desired, and electrodes of various shapes and sizes are covered by a halo of light of a color determined by the kind of gas used. Lamps of this type ranging in rating from $^1/_4$ watt to 3 watts are used in a great variety of novel applications, from gunsights and switchboard indicators to night lights and exit signs. Lamps of this type are entirely self-contained in the sense that their ballasting resistance units are built into the lamp structures themselves so that no external devices are required, and the lamps ordinarily may be screwed directly into standard incandescent lamp sockets.

Fluorescent lamps are the result of a very recent and interesting development. While none actually have been standardized for general sale, they are rapidly taking the form of tubular sources ranging from 12 to 50 inches in length and about one inch in diameter. The light from an incandescent lamp is characteristic of the filament temperature only, and that from a gaseous-conduction lamp is fixedly characteristic of the gas used; in these fluorescent lamps, however, the quality of the light is characteristic of the fluorescent material used, from which it follows

that primary light sources may be made in which the color possibilities are limited only by the almost innumerable kinds of fluorescent materials available. In addition to the variety of pastel shades available, this method of light production has made possible for the first time high efficiency in the production of colored light. In lamps ranging in wattage from 10 to 125 watts, efficiencies from 25 to 100 times as great as those of correspondingly low-wattage incandescent sources have been obtained, depending, however, upon the color of light on which the comparison is made.

The modern use of built-in provision for interior lighting, together with provision of air conditioning which makes windows for ventilation no longer necessary, has opened up a field for so-called combination lighting, in which a small amount of mercury light is added to incandescent light to secure a blue-white quality often desirable. Since only the blue part of the mercury spectrum has been needed for this purpose, the smaller sizes of Cooper-Hewitt mercury lamps have been found satisfactory for this work in spite of their inefficiency as compared with the newer high-efficiency lamps. It is thought the new 85-watt high-efficiency lamp may find considerable application in such combination fixtures. Another type of combination lamp finding some use for show-window and spectacular lighting is made up of hot-cathode mercury and neon lamps. The quality of the light from such combination lamps, although pink-white in its subjective effect, has the property of slightly modifying the appearance of colored objects in a manner sometimes found desirable, notably in the lighting of florists' windows and in other similar cases where fidelity of appearance may not be as necessary as a spectacular effect.

Ultraviolet Sources

There have been no major changes in the ultraviolet sources reported in 1932. A larger glow lamp has been introduced known as the "*G*-5" glow lamp. The lamp itself consumes about 75 watts, and together with transformer approximately 100 watts. It has a starting voltage of 40 to 50 volts, an operating voltage of 14 to 16 volts, an operating current is 5 ampers, a light output of approximately 700 lumens, a "*G*-35" bulb, a special "No. 1864" base, and an ultraviolet output approximately twice that of the "*G*-1" glow lamp. Both the "*G*-1" and "*G*-5" glow lamps have been made available as special lamps in black ultraviolet transmitting glass which filters out the visible light and enables their use for producing fluorescent and phosphorescent effects without the use of auxiliary filters.

The 300-watt "mazda *CX*" lamp has been replaced by a 250-watt "mazda *CX*" lamp in a "*G*-30" inside frosted bulb with medium screw base.

The types "*S*-1" and "*S*-2" sunlight lamps are the ultraviolet sources that have found the widest application for health purposes during the past 4 years. Their largest field has been in the home, as both floor and table lamps are available. They have been used to a considerable extent in swimming pools, hospitals, and to a limited extent in schools and offices, and in animal and poultry husbandry. In the 2 latter fields, however, the "*CX*" lamps have grown steadily in their application.

There is an increasing use of ultraviolet radiation for fluorescent and phosphorescent purposes, both commercially and for display and entertainment. Some of the large laundries now are marking clothes with fluorescent inks which under ordinary lighting are invisible but show up under ultraviolet lamps. Fluorescent inks have also been developed which can be used in ordinary lithographic work, and they are having some application in the printing of advertising posters.

A new gaseous conduction lamp recently has made its appearance on the market, known as the "sterilamp." Although it is not classified as a source of visible light, its invisible ultraviolet radiations of selected wave lengths has produced some startling results in the field of sterilization. It is expected that this lamp will find wide usage in many food industries and to some extent in hospitals.

Carbon Arcs

Since the last report there have been 3 outstanding developments in the application of the carbon arc to motion picture projection. These are the a-c high-intensity arc, the so-called "suprex" type of arc, and the super-high-intensity arc.

The a-c high-intensity arc, as the name implies, operates through a transformer of suitable voltage ratio without rectification of the a-c power supply. The "suprex" type of arc uses a similar carbon designed for operation on direct current. Both of these arcs use copper-coated carbons which are not rotated in operation. In this respect they differ from earlier types of high-intensity arcs. Furthermore, they are adapted to operation with much lower power consumption than had previously been possible. These new developments have brought high-intensity projection, with its advantages of more brilliant screen illumination and a higher permissible level of general illumination, within the economic reach of theaters of small and intermediate size.

The super-high-intensity arc, using a 13.6 millimeter positive carbon and operating at arc currents of 140 to 190 amperes, meets the needs of theaters with very large screens and very long throws. This new carbon gives more than 30 per cent increase of screen illumination over that provided by the 13.6 millimeter regular high-intensity carbon operated at 130 amperes. It also has more uniform distribution of brilliancy across the crater face, resulting in more uniform distribution of light over the screen.

In the motion picture studio, a new studio lamp with silent arc control mechanism has been designed for broadside lighting and scoops. It uses a special metal-coated white-flame carbon developed for this specific purpose. These carbons are operated at current densities closely approaching those used with the high-intensity arc, and the resulting arc, although essentially a flame arc, gives a light that has many of the characteristics of the high-intensity arc. For all practical purposes, this light is photographically equivalent to natural sunlight. The color balance

for modern photographic emulsions and the efficiency in light production are considerably improved over the regular white-flame carbon. Although developed primarily for color photography, where it has proved a necessity, the excellent color balance of this light and the resulting improvement in photographic effect are extending its use into black-and-white production.

High-intensity sun arcs and rotary spotlights have been greatly improved during the past 2 or 3 years, adapting them to use in sound productions. The mechanisms of these lamps have been silenced so that they can be used in reasonable proximity to the microphone without disturbing effects. The use of the Fresnel lens on the new rotary spotlights and the 24-inch sun arcs has resulted in a substantial increase in light pick-up together with the elimination of dark centers when the beam is spread to flood.

In the field of light therapy the development of high-intensity therapeutic carbons and the adaptation of professional-model carbon-arc lamps to their use have provided a source of ultraviolet radiation for individual irradiation of higher intensity and efficiency than heretofore has been available. A twin-cot lamp also has been developed for use with these carbons. This is designed to be placed between 2 cots so that 2 patients can be irradiated at the same time from one arc.

The past few years have seen increasing use of the carbon arc in industry as a source of ultraviolet radiation. Paint tests and numerous industrial processes, many of which are of a confidential nature, are included among these applications. The outstanding development in this field has been the irradiation of milk for vitamin *D* activation. Many producers throughout the country are now irradiating a substantial portion of their fluid milk supply. In addition, dry milk and evaporated milk are being supplied in irradiated form. The carbon arc has been most widely accepted as a source of ultraviolet radiation for this purpose since it has a high emission of those wave lengths that have been found most effective in vitamin *D* activation.

A small portable carbon-arc lamp is finding increasing application as a source of ultraviolet radiation essentially free from visible light. The carbon arc is entirely enclosed, and its radiation is emitted only through a glass filter which transmits ultraviolet radiation readily but passes only a trace of visible light. This lamp is being used in laboratories for analysis by fluorescent effects and is also finding application in crime detection. Examination of documents for evidence of erasure or other fraud and the inspection of letters for invisible writing are examples of the latter application, while the recent announcement of a method for the quantitative determination of vitamin *G* by fluorescent analysis indicates the possibilities of this lamp in laboratory investigations.

New Materials for Lighting

About 2 years ago announcement was made of a method of improving the reflecting surface of aluminum by anodic treatment known as electrolytic brightening. Ordinarily polished aluminum has a reflectivity of 65 to 75 per cent, while the new so-called "alzak" aluminum has a reflection factor of from 80 to 84 per cent and a much higher resistence to marking by handling and even to ordinary corrosive conditions, such as weather exposure. "Alzak" aluminum has very properly been used in many recently designed reflectors of the specular type.

Most marble in thin sheets will transmit some light, but until recently it was not believed possible to obtain the natural stone in such thicknesses as to have the requisite strength and yet possess a reasonably high light transmission. During the past year one of the leading marble quarries has discovered a means of selecting marble panels that possess the desired property. This new form of marble, known by the trade name "lumar," transmits a reasonable amount of light, the definite percentage depending somewhat on thickness and quite considerably on configuration and the amount of colored material in the pattern. It also has the property of reflecting light very well, and since a relatively small amount passing through the marble is sufficient to render it pleasingly luminous, the lighting engineer now has a new tool with which to work.

The extensive introduction of organic plastics into many industrial fields has included the field of illumination. Molded forms such as indirect or semi-indirect bowls, wall brackets, ceiling domes, and reflectors for "I.E.S. study lamps" have found acceptance. Optically, plastics compare favorably with glass in diffusion, reflection, and transmission, although in the last quality glass is somewhat superior. Light in weight and rugged, plastic forms solve many shipping problems and for the same reasons are particularly useful for transportation lighting equipment. Sheet plastics available in various finishes, colors, and thicknesses, noninflammable and flexible, have found applications in built-in lighting, in decorative lighting for expositions and celebrations, in display advertising, and in window trimming.

New Reflecting Equipment

There have been many developments in all classes of equipment, industrial, commercial, aviation, street, residence, floodlighting, etc. Some of these are radically new and others are logical developments from past practice. In the industrial field, one especially worthy of note is called a "sup-lite." This was developed for the purpose of producing increased lighting intensity at points where the severity of visual task dictates plenty of light. It employs a 150-watt lamp, is louvered to reduce brightness, and produces 100 foot-candles at a distance of 5 feet.

An interesting line of equipment utilizes elliptical reflectors. The ellipse has the property of reflecting light originating at one focus to the secondary focus. New constructions of concentrated filament lamps and new reflecting materials made the elliptical reflector more practical than ever before. One form of this is known as a "down light" and makes it possible to control light emerging through a very small opening. The entire auditorium of the Center

Theater in Rockefeller Center, New York, is illuminated by approximately 200 "down lights" of the 100- and 250-watt sizes. Somewhat similar, smaller units employing 50-candlepower automobile headlight lamps are used to illuminate the table area in the Boardwalk Café, Jones Beach, Long Island, N. Y.

The elliptical reflector principle also has been used in a series of spotlamps for theaters. With this arrangement much higher light outputs are obtained than were possible with the old-style spotlamp with plano-convex lens. It is also possible, through the use of a suitable shielding or shutter arrangement, to control definitely the shape of spot, and very fortunately this accurate control is attained without serious loss of light.

Automotive Lighting

The radical changes in the construction and appearance of the modern automobile has been accompanied by similar improvements in the design of lighting systems.

The first headlighting system developed about a 3-filament lamp and providing asymmetric beams was used on one of the 1932 cars. Succeeding headlighting systems with this type of beam were developed later in conjunction with 2-filament lamps and are used on many of today's automobiles.

The following year the prefocused headlight lamp was introduced and is now used as initial equipment for all cars. This lamp has the filament located with reference to a flat prefocusing collar accurately secured around the usual base of the lamp and having 3 projections which bear directly on the reflector. The maximum allowable tolerance is ± 0.01 inch, $^1/_3$ of the former value. The collar also serves as a more accurate means of locating and holding the light source in the reflector and has made possible the use of reflectors of shorter focal length and smaller diameter having a more satisfactory lighting performance than the previous larger types. There was also introduced a change in bulb shape which minimized "filament image" and "phantom" beams.

The development of an indicator lamp with a miniature bayonet base and minimum physical dimensions has resulted in an increased application of "light" signals for the convenience of the car driver. Beam indicators and lighted heater switches are in general use, and various instruments have been replaced with such a device.

A new headlighting system, introduced on several of the 1936 cars, employs 2 beams, the first resembling the upper or clear road driving beam of previous conventional systems and the second deflected sharply to the right as well as slightly down. The lamp used has 2 bar filaments in place of the 2 "V" filaments of previous types and can be used only in headlighting systems specifically designed for it.

Considerable thought and time is being given to the problem of automotive lighting and, in addition, every effort is being made to improve road lighting and promote safety on the highway. Shielded headlight bulbs have found some application in reducing "spill" or scattered light, thus improving visibility when driving through fog or haze.

School Lighting

Ideas of school building construction and methods of instruction have changed rapidly during the last decade. Recent years have witnessed a gradual awakening of school authorities to the fact that the best buildings, teaching methods, and equipment cannot function properly unless adequate lighting is provided for the school rooms. Further, it has come to be realized that inadequate and poor lighting contributes materially to eye strain and eye fatigue and these, if long continued, result in impaired vision, a reduced rate of progress in work, and lowered efficiency.

A new "Standards of School Lighting" was adopted as an American Standard in the fall of 1932 and is now being brought up to date.

Lighting science also has progressed and during the last few years we have progressed from a science of vision to a science of seeing; the result is a profound and fundamental change in the viewpoint—from merely seeing to ease of seeing—and new scientific and more exact knowledge on the lighting needed for specific seeing tasks.

Today for ordinary seeing tasks in classrooms, 20 foot-candles are in use. Materially higher levels are needed for finer work, such as drawing and sewing, while children with defective sight need levels of from 30 to 50 foot-candles. Automatic control of lighting in school rooms is practical and economical, and assures sustained, adequate levels of illumination, irrespective of the daylight conditions.

There is a rapidly growing appreciation of the close relation between lighting and student achievement and of the fact that good lighting is a most important economic and social factor in school life.

IES Study and Reading Lamp

In the fall and winter of 1933 the industrial and school lighting committee of the Illuminating Engineering Society initiated a survey of the lighting conditions in study rooms of colleges and fraternity houses. The prevalence of deplorable lighting conditions was found to be almost universal, lighting devices available inadequate, and seeing conditions contributing to defective vision and eye strain.

One outcome of these studies was the development of a lamp, since known as the "IES study and reading lamp," superior for study and reading purposes and providing adequate and comfortable illumination economically and efficiently. The value of the development was so apparent that specifications were issued by the Illuminating Engineering Society and a certification plan adopted. To date well over 1,000,000 of these lamps have been made and doubtless are in use.

Later specifications cover, in addition, the wall type and floor type of lamps as well as semi-indirect and indirect lamps of larger light output.

The performance of the study and reading lamp has been adopted as a standard by both the English and French manufacturers and has had a material influence on the design of portable luminaires in general.

Notable Lighting Installations

Most of the outstanding, unique lighting installations in the United States are described in the monthly reports of the committee on light in architecture and decoration of the Illuminating Engineering Society, which are published in the *Transactions* of that organization; those interested in details are referred to those pages.

Many outstanding applications of artificial illumination are to be seen in the group of buildings in New York known as Rockefeller Center, or more popularly as Radio City. Space does not permit the tabulation of even a representative list, but as a matter of record one must mention the new Union Depot at Cincinnati, Ohio; The War Memorial Opera House, San Francisco, Calif.; the State Educational Building at Harrisburg, Pa.; the Riverside Church, New York, N. Y.; the Niagara-Hudson-Syracuse Lighting Company Building, Syracuse, N. Y.; the new group of buildings at Hershey, Pa.; the G. Fox and Company store at Hartford, Conn.; Wm. Rockhill Nelson Gallery of Art, Kansas City, Mo.; and the Steamship "Normandie" of the French Line.

With the repeal of prohibition there has been a remarkable renaissance in restaurants, cafes, and cocktail lounges. Almost without exception the more pretentious of these use interesting lighting effects as the dominant decorative note.

The "Century of Progress" exposition at Chicago mentioned in the last report came into being as scheduled and was carried on successfully for 2 consecutive years. The visitors were practically unanimous in declaring that the night effect was far superior to the appearance by day. The San Diego (Calif.) Exposition of last year possessed a number of most pleasing spots of lighting and particular advantage was taken of the natural foliage and other elements of the setting as a background for illumination. The Exposition at Brussels, Belgium, was a veritable gem of artificial lighting and the ideas were carried out in a delicate, restrained manner. The lighting effects at the Texas Centennial Exposition in Dallas (see pages 1060–74, this issue) and the Great Lakes Exposition in Cleveland, Ohio, are evoking favorable comment. Plans are already under way and experiments have been conducted for devising outstanding and original illumination schemes for the projected Paris, France, exposition of 1937.

Architectural Lighting

There is scarcely a major project where the designing architect does not give consideration to lighting at the proper time. This is early in the planning, for the best effects of modern lighting can be obtained only when it is considered along with the structural elements. The architects of the future will be even more cognizant of this fact for many of them have participated in the *beaux-arts* prize competition of the Illuminating Engineering Society. The subjects for the last 5 years have been: A great hall for the electrical building at a world's fair; general waiting room of a railroad station; the interior of a church; a bank for savings; and an automobile salon. On these various projects approximately 1,000 students have submitted drawings and designs, and it is obvious that one cannot work intimately with lighting problems without becoming aware of the potentialities and, in turn, putting his ideas into practice at a later date.

Science of Seeing

The art and science of illumination is in one respect as old as man, but from another viewpoint not much more than 25 years old, for intensive study of artificial lighting came into being with the founding of the Illuminating Engineering Society. These last few years have brought forth a wealth of information on all phases of light and its relation to vision. Until recently, however, only a relatively few specialists were aware of the salient points. Since the last report of this committee, however, there has been an intensive, literally worldwide, campaign of popular education. The important features of this partnership of light and sight have been described in simple nontechnical language. The message has been taken to the school child, the housewife, and the business man. The ramifications of this campaign of education are too vast to be outlined here. It is a movement in which many industries and organizations have co-operated, and it may be reported that today almost everyone who reads or listens has at least some small concept of the fact that proper light is essential to comfortable vision. The whole movement is known as the "better light, better sight" activity.

Light Measuring Instruments

The popularity of portable illuminometers employing light-sensitive cells has increased definitely during the last several years. Several different makes are available.

None of these light-sensitive cells has a spectral-sensitivity curve that corresponds exactly to that of the eye. There are 2 general methods for correcting this deficiency—the use of a gelatin or colored glass filter, and the use of correction factors depending upon the spectral characteristics of the light source being measured. The use of filters has met with some difficulties due to the proper selection for complete correction and also due to the loss of cell output from absorption of the filter. The use of multiplying factors meets with some difficulty because of the wide variation in spectral characteristics of light sources requiring a different factor for each one, and also because of the variation in response of individual light-sensitive cells. Further development of these cells undoubtedly will improve the accuracy with which they may be used for photometric purposes.

Visibility Meter

The visibility meter is a new instrument for appraising the visibility of various objects and visual tasks and for specifying practicable levels of illumination for visual tasks upon a rational basis. The in-

strument consists essentially of 2 colorless photographic filters with precise circular gradients of density which may be rotated simultaneously in front of the eyes while looking at an object or while performing a visual task. The observer holds the instrument in approximately the same position that eyeglasses are worn and with a finger of the right hand slowly turns a disk which rotates the circular gradients until the visual threshold or limit in the performance of the visual task is reached. Individual measurements of visibility may be made in a few seconds, even by relatively untrained observers.

Transportation Lighting

During the past 2 years rapid strides have been made in railway and motor-coach lighting. Because of low efficiency and poor maintenance, totally indirect lighting, which was tried for awhile, is slowly being discarded in the newer trains in favor of the semi-indirect louvered trough and totally direct systems. As a result much higher intensities are coming into use.

In the electric railway field, new car equipment is being supplied with lighting systems delivering 15 to 20 foot-candles on the reading plane. Systems of unique design utilizing continuous louvered lighting troughs and enclosing glassware have been used.

The motor coach industry rapidly is improving lighting conditions with lighting systems employing an individual unit directly above each seat. The modern coach is being lighted to the extent of 8 to 10 foot-candles on the reading plane. In general, the lighting equipment is of the concentrating type, light control being secured either by means of lenses or glass-enclosed metal reflectors.

Artificial Light in Floriculture

During the past 4 years there has been quite an increase in the use of artificial light for stimulating plant growth. A steadily increasing number of commercial greenhouses are using lamps in order to force their flowers into early bloom and get them into high-priced markets. The latest practice in this connection is getting away from small lamps on drop cords hung close to the plants, and going into the more-efficient higher-wattage lamps mounted near the roof of the greenhouse.

A rather interesting type of greenhouse has been developed and placed on the market. This is a heat-insulated greenhouse which, with the exception of one side of the roof, is made entirely of heat-insulating material instead of glass as in the ordinary greenhouse. Incandescent lamps are used in this house to supply all the heat required and to supplement daylight for plant growth. The lamps are thermostatically controlled. Better plants have been raised in this type of house and in a shorter period of time than has been possible in the ordinary greenhouse.

There has recently been placed on the market by several of the leading fixture manufacturers a line of plant lighting fixtures with holders for flower pots. Tests have shown that by means of these, many plants can be grown successfully in locations well removed from windows.

Some experimental work also has been done in the use of lamps for heating hot beds.

Outdoor Sports

Favorable power rates and the development of inexpensive and efficient floodlighting equipment has made possible the economical illumination of sports fields for night play. The practice has resulted in increased gate receipts and in greater opportunity for recreation in public parks, schools, and other places. The first major-league baseball park to be illuminated for night play was Cincinnati's Crosley Field where 1,050 kw of floodlighting provides an average illumination over the field of approximately 70 foot-candles. In sports lighting the hours of operation are relatively short, and it is found advantageous to operate incandescent lamps above their rated voltage. The common practice of designing the distribution circuit to deliver a voltage 10 per cent greater than the rated voltage of the lamps results in approximately 35 per cent increase in light output with an increase of only 16 per cent in power consumption. The resulting lamp life of approximately 300 hours is, in general, ample for a season's play. The energy requirements for the more common sports are approximately as shown in the following table using 1,500 watt units of both the open and enclosed types:

Baseball (regulation)	100 to 300 kw
(soft-ball)	15 to 50 kw
Football	50 to 100 kw
Ice hockey	15 to 25 kw
Shooting trap	8 to 15 kw
skeet	10 to 15 kw
Tennis	12 to 18 kw

The illumination of swimming pools by means of overhead and underwater lighting is considered an essential feature for modern pools. The underwater lighting system is found to be particularly effective as a safety measure, as a means of observing swimmers undergoing instruction, and as a sanitary measure.

Street and Highway Lighting

The appalling array of statistics showing current highway accidents and fatalities and the equally startling proof that adequately lighted streets and highways will materially reduce this unnecessary loss of life and property damage has stimulated a more intense study of this subject. In street and highway lighting there is a trend toward higher levels of illumination, closer spacing of units, higher mounting heights, and greater shielding in the interest of better seeing and the elimination of objectionable glare. Recent developments in street and highway luminaires have shown an improvement of from 50 to 100 per cent in utilization on the road over the prevailing types of a few years ago.

Gaseous light sources of the sodium type generating 55 lumens per watt and the high-intensity mercury type generating 40 lumens per watt, have been developed, together with suitable reflecting equipment, so that they now are important factors in current street lighting design. The sodium lamp in sizes of 6,000 and 10,000 lumens are installed along many miles of trunk highways and bridges throughout the country. Combination incandescent and mercury-vapor lamps offer a pleasing quality of light for city business streets and show an advancement in over-all efficiency over the incandescent type of unit.

A more sensitive type of photoelectric control for street lighting systems combined with greater flexibility is now finding many practical applications in control.

Aviation Lighting

Simplification and standardization has been the keynote of recent developments in aviation lighting. The 36-inch double-end beacon designed by the airways division of the United States Department of Commerce is standard for airways. A new type of beacon incorporates the features of the rotating and flashing beacons. It consists essentially of a glass sphere 36 inches in diameter into which are built 3 systems of lenses. The effects of these 3 lenses are to provide: (1) a principal beam practically horizontal; (2) a beam extending for 270 degrees around the beacon with its lower edge horizontal and its upper edge approximately 24 degrees above the horizontal; (3) a top or ceiling light producing a wobbling effect as the complete unit revolves.

The marking of airport boundaries and obstructions continues to be done by clear and green lights for the former and red lights for the latter, using both series and multiple distribution with lamps of 15 to 100 watts in the multiple service and 320 to 1,000 lumens in the series service. Lamps are enclosed in prismatic globes and are mounted on tip-over cones on series circuits and fixed cones on multiple circuits. The airways division regulations pertaining to the marking of obstructions, particularly those relating to floodlighting, are not as definite as appears to be desirable and might to advantage be revised.

For floodlighting, government specifications require a vertical illumination of 0.20 foot-candle instead of 0.15 foot-candle formerly specified. In view of the relatively short hours of operation and resulting low power consumption, it appears in order to increase the level of illumination on landing areas in the interest of safety and efficiency. Where it is impractical economically to illuminate the entire area within the field boundaries, it has been found quite effective to floodlight the runways only from each end. Field floodlights with parabolic reflectors, diverging door glasses, and 1.5- and 3-kw 32-volt lamps commonly are used, either singly or in groups for this service. The general subject of runway marker lights and approach lane marker lights is being studied as a supplement not only to field floodlighting, but also to the radio systems for bad weather landings and take-offs.

Lighting Control

Thermionic tube control combined with saturable reactors has met popular acceptance where smooth gradation of brightness is desired and for truly preset switchboards. During the last 4 years notable installations have been made in the Radio City Music Hall, Center Theater, and Metropolitan Opera House, New York, N. Y. Simple, flexible controllers for the floodlighting of buildings and decorative fountains, and for ballroom and show-window lighting have been developed. In these, changes in the total duration of the lighting cycle can be made quickly by a change in gears, and the lighting program can be varied by adjusting cams.

Small pilot controllers also have been supplied for night clubs, school auditoriums, and small theaters; these can be mounted flush on a wall in convenient positions for observing the effect. A 4-circuit board of this type with master controller is only 16 inches high, 13 inches wide, and 6 inches deep.

The uses of photoelectric tubes and relays constantly are being extended. Street-lighting control school-room lighting, timing of races, operation of restaurant doors, safety control of elevator doors, and similar uses indicate a rapidly growing field.

Meeting of International Commission on Illumination

The work of the International Commission on Illumination and of the United States National Committee on which the AIEE is represented is conducted in triennial cycles. The latest cycle, which had been extended to 4 years by postponement, culminated in the convention of the commission held in Germany in July 1935. Reports of 26 technical committees were presented and discussed in meetings at Berlin and Karlsruhe, and formal conclusions and recommendations were submitted.

The character and significance of the accomplishments may be indicated by brief references to a few specific actions.

One of the important examples from the practical viewpoint was in the field of aviation where the aircraft and ground lighting committees produced extensive outlines of recommended principles, rules, and specifications to guide practice, and legal regulations for effectiveness and safety. These recommendations obviously are based upon the world's best knowledge and come at a time when modifications of practice still can be made. Thus they are destined to render a service of very material value to the art of night flying and so to world commerce.

The commission confirmed the decision made in 1924 to base the primary standard of light upon the radiation of a black body, and in accordance with the suggestion of the special committee on photometric units and standards to adopt, for the temperature of this black body, the temperature of the solidification of platinum. This action seems to assure the general acceptance of definite specifications

within 3 or 4 years. The purpose of this standard is to prevent a gradual drift in the magnitude of the unit of candlepower due to possible changes in the incandescent lamps by which this value now is maintained.

Another action closely related to the foregoing is expected to eliminate immediately the serious international discrepancies in the photometry of gas-filled tungsten lamps and to minimize the wide variations in the measurements of gaseous-discharge lamps. While both of these apply more directly to laboratory work, their influence will be felt in all lighting work including the commercial phases.

The lighting vocabulary with equivalent terms and definitions in English, French, and German was extended considerably. Authorization was given for the publication of this material in pamphlet form with the addition of the corresponding Spanish and Italian terms.

It seems certain that the commission will continue to function with increasing activity as an independent organization. An obvious factor in this connection is the powerful influence wielded in Europe by the proponents of gas lighting. However, a more fundamental reason for maintaining a separate organization is the importance of the artistic, physiological, and psychological phases of illumination. It appears impracticable to provide adequate consideration of these elements through any organization devoted to those fields of engineering that are based essentially upon physical science.

By their initiative in applying practical considerations, American illuminating engineers contribute much to European progress, while in turn the painstaking application of theoretical considerations and the conservative regard for ultimate objectives exhibited by European illumination authorities help guide American engineers toward sound practice.

Carrier Relaying and Rapid Reclosing at 110 Kv

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This paper describes an application of carrier-current relaying combined with rapid reclosure of circuit breakers by means of which the continuity of service to a large industrial load supplied by a long single-circuit line was improved. A 110-kv line 120 miles long, forming part of an interconnected loop, has been equipped in this way to clear faults and restore service in approximately one second. The effect of the connected motor load on circuit interruption is also discussed.

FOR ECONOMICAL service on the interconnected transmission systems of the Arkansas Power & Light Company, Louisiana Power & Light Company, and Mississippi Power & Light Company, in the lower Mississippi valley, individual high-voltage circuits are necessarily of considerable length and simple design and must perform the dual function of trunk interconnections and load feeders.

From one of the 110-kv 120-mile trunk interconnecting loop circuits, between the Sterlington steam station and Indianola substation, is served the city of Greenville, Miss., which has important paper-mill, cotton-gin, and manufacturing load. Considerable power also is used in the various processes of manufacturing insulating board and wallboard from wood fiber in the plant of the U.S. Gypsum Company at Greenville.

Early in 1935 the necessity for improved continuity of power supply to the essential manufacturing processes was indicated. Through co-operative studies between the interested organizations, a program was decided upon to:

1. Decrease the interruptions to manufacturing processes through improvements in relaying and control of the circuits within the substation and mill of the power consumer (figure 1).

a. Provide the necessary co-ordinated relaying within the plant

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to protect the apparatus in case of faults inside the plant and to disconnect all apparatus in case of continued loss of supply voltage, that is, time-delay low-voltage tripping.

b. Obtain certain electrical regrouping of apparatus and circuits to co-ordinate essential and nonessential units.

2. Improve the continuity of the high-voltage power supply to the U.S. Gypsum plant.

A study of the operating record for the past 4 years showed that for the 120-mile Sterlington-Indianola line there were an average of 27 interruptions per year caused by lightning and that these constituted about 90 per cent of all interruptions experienced, with the exception of those resulting from prearranged operations.

Several plans to improve the continuity of power supply from the 110-kv line were studied and it was decided, from both an engineering and economic standpoint, that improved relaying and automatic-reclosing circuit breakers in the Sterlington-Indianola line would materially improve the service supplied over the line. Thus the reclosing breaker and carrier-type relaying would make the single-circuit line practically equivalent to the conventional double-circuit line so far as the effects of lightning disturbances were concerned, thereby improving the reliability of power supply to the consumer.

With the installation of a pilot scheme of relaying, using a carrier-current channel over the transmission circuit, high-speed relaying and simultaneous breaker tripping at both ends of the line could be obtained. Simultaneous tripping of both breakers would permit, within reasonable time limits, the application of rapid automatic reclosing of one or both of the line breakers. With improved relaying and standard modern breakers all faults regardless of location or severity may be cleared in from 12 to 14 cycles or less, thus preventing not only some of the interruptions that were prolonged, but making unnecessary many of the prearranged interruptions needed for line maintenance. Following the rapid clearing of faults on the 110-kv line, automatic rapid reclosing of one of the breakers would restore service with a total estimated period of low voltage at the power consumer's premises of the order of one second or less. With the power consumer's control equipment properly co-ordinated, it was concluded that the essential loads supplied from the line would not be adversely affected and that service essentially free from lightning influences could be supplied over the single-circuit line.

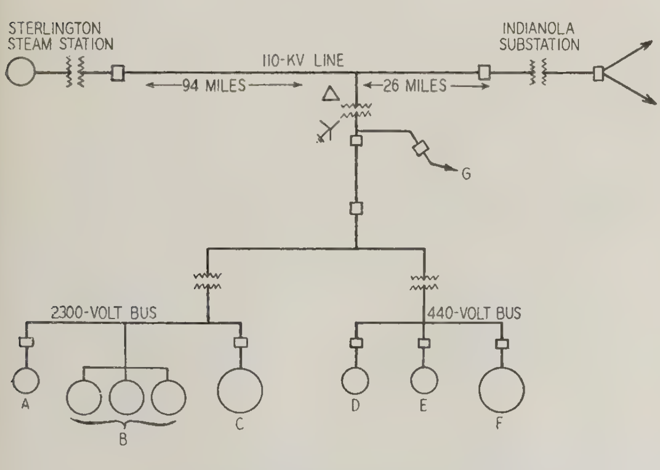


Fig. 1. Schematic diagram of a 120-mile section of the interconnected loop transmission system showing consumer's load

A—Exciter set and flywheel motor-generator set
B—Three 700-horsepower synchronous motors
C—1,800-horsepower synchronous motor
D—Synchronous motors for kilns
E—Synchronous motors for vacuum pumps
F—Plant induction motors, total capacity 2,500 horsepower
G—City of Greenville general light and power load (no synchronous motors)

A—1,800 - horsepower motor, full load

B—700 - horsepower motor, 1/3 load

C—700 - horsepower motor, 2/3 load

D—700 - horsepower motor, full load

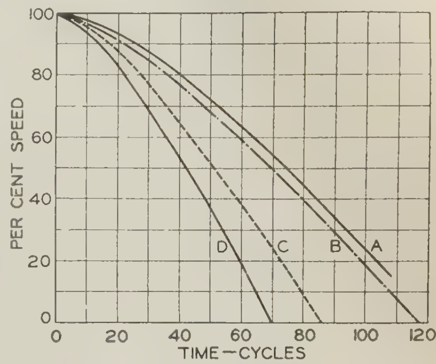


Fig. 2. Curves of deceleration of synchronous motors

Factors Influencing Time of Breaker Reclosing

Figure 1 shows the portion of the electric system and customer's apparatus that is involved in the considerations that enter into the clearing of faults resulting from lightning on the 110-kv circuit, and subsequent reclosing of the Sterlington breaker.

The factors affecting the over-all time for reclosing may be considered under 4 headings as follows:

1. Time required for relaying and breaker opening.
2. Time required for arc extinction and deionization.
3. Time required for reclosing breaker.
4. The sum of the time elements under 1, 2, and 3 must be less than a minimum time to prevent interruption of the essential manufacturing processes.

The general problem of arc extinction on high-voltage lines supplying industrial plants of this kind is complicated because the opening of the high-voltage breaker does not necessarily de-energize the line, as synchronous and induction motors in the consumer's plant may provide the necessary energy to maintain the arc. Thus careful study and co-ordination of the various factors of the problem are required.

Supply Breaker Opening. The use of a carrier-current channel and associated relaying between Sterlington and Indianola permits simultaneous tripping for all faults within the line section and assures that false tripping will not occur for disturbances outside the protected section. Thus a definite period of time for tripping both breakers at

the line ends is assured. The breakers at both ends of the line were of the type that could be modified readily to increase their speed of opening. It was estimated that the combined time of relaying and breaker opening would be of the order of 12 cycles. Other factors described later indicated that higher-speed relaying and breaker opening would not be justified economically in this case.

Motor Drives. The motor capacity in the U.S. Gypsum plant consists of 4,000 horsepower in synchronous motors and approximately 2,500 horsepower in induction motors. The synchronous-motor drives are classified as nonessential units with respect to continuous plant operation, and it was the general opinion that all synchronous drives should be disconnected from the circuit as rapidly as possible in the event of trouble on the supply source, thus eliminating the effect on arc extinction of synchronous motors feeding back into the fault.

It was recognized that the connection to the 120-mile 110-kv transmission line would result in a strong tendency toward self-excitation of the induction motors after the synchronous motors were disconnected, thus permitting the induction motors to hold up the voltage and supply the line losses and Greenville load. This would retard arc extinction on the 110-kv circuit. However, this load would be in the direction to decelerate the induction motors more rapidly than was indicated by simple calculations. Thus, it was decided that the relaying equipment, reclosing breakers, etc., to be installed would be capable of operation in a much shorter period of time than that indicated by the preliminary data on induction-motor drives and that the time of actual reclosure should be determined by a test involving the system and plant apparatus at the time of installation. It was estimated that the high-voltage relaying system, reclosing control, and modified Sterlington breaker were to be capable of operation in a minimum period of time of the order of from 38 to 40 cycles, that is, from the time of fault to complete reclosure.

Large Synchronous Motors. It was felt that the large synchronous motors driving pulp grinders would fall out of step under certain types of faults within 5 or 6 cycles. For this reason and also because of their detrimental effect on arc extinction it was decided to disconnect the motors upon indication of loss of power supply.

Relaying of Synchronous Motors. Both power-directional and frequency relays were considered as the means for tripping the synchronous-motor breakers. Studies showed that a positive indication for tripping motors would be afforded by the use of frequency relays and that the time available for such operation was within the over-all time permissible for reclosure. Power-directional relays were considered unfavorably because of the time delays required to avoid improper operation under certain conditions of system oscillations which may arise as a result of faults outside of the carrier-current zone. A standard type of frequency relay was selected to indicate the drop in frequency always associated with loss of supply voltage and to initiate breaker tripping for disconnecting the synchronous motors from the line.

Arc Extinction. Very little data are available on the characteristics of arcs in the open air or across wooden crossarms, etc., when some percentage of normal voltage is impressed across the arc space. The opening of the high-voltage breakers disconnects the line from the main power source, but the conductors are still excited from the synchronous motors at a frequency set by the synchronous motor speed and at a voltage determined by the characteristics of the synchronous-motor electrical load and line characteristics. When the synchronous motors are disconnected the possibility exists of the capacity effect of the transmission line causing the induction motors to be excited from the line at a frequency set by the circuit constants. The induction motor constants will vary with slip and saturation. It was the opinion of interested engineers that after disconnecting the synchronous units within the plant the arc would be extinguished within a sufficiently short period of time to fall within the proposed cycle of operation, and with an additional

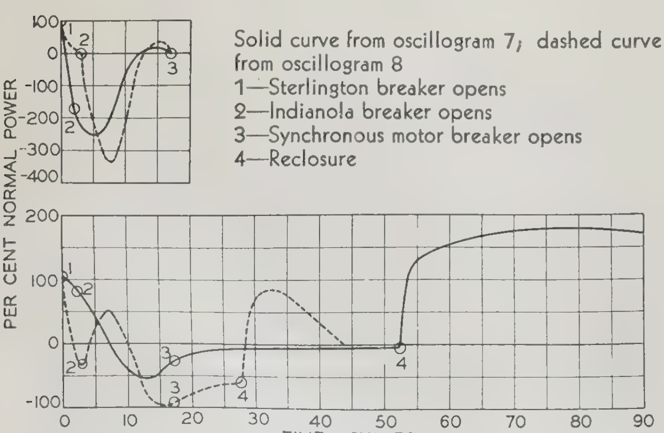


Fig. 3. Oscillograms of synchronous-motor power (upper) and induction-motor power (lower) from staged test with no fault on line

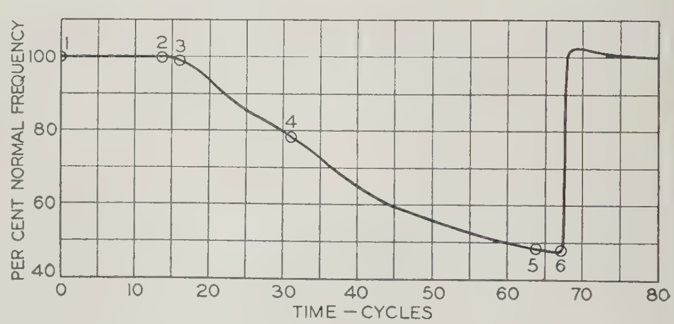


Fig. 4. Curve obtained from oscillogram 11 showing deviation of the frequency from normal 60 cycles during a single-phase-to-ground fault at Greenville substation

1—Fault occurs
2—Sterlington breaker opens
3—Indianola breaker opens
4—Motor breaker opens
5—Arc extinguished
6—Reclosure

period of the order of from 5 to 7 cycles to allow for deionization of the air space full voltage could be reestablished without causing a subsequent reignition of the arc.

Requirements of Reclosing-Control Apparatus. Because of local circuit conditions it was decided that the Sterlington breaker should be the only one to be reclosed automatically, and that the Indianola breaker should be reclosed by the station operator after synchronism was checked.

It was decided also that the time of the reclosing cycle should be adjustable from a minimum of approximately 38 cycles to a maximum of 3 seconds because of the uncertain factors in the time for total reclosure.

To prevent "pumping" of the Sterlington breaker, it was decided that only one open-close-open operation should occur in any 3 second period. If such a cycle of operation should occur it would be indicative of a fault that could not be cleared readily or would be caused by repetitive lightning strokes. In such cases the breaker should be locked out and closed again only under supervision of the operator. If the supply breaker could be reclosed and remain closed for a time period of the order of 2 seconds the plant motors would regain normal speed and the cycle of operation could be repeated. Thus if subsequent lightning strokes occur after reclosure but before the motors accelerate to normal speed the reclosing sequence should be locked out. If the subsequent stroke occurs after acceleration is accomplished the sequence should be set up for the normal reclosing cycle.

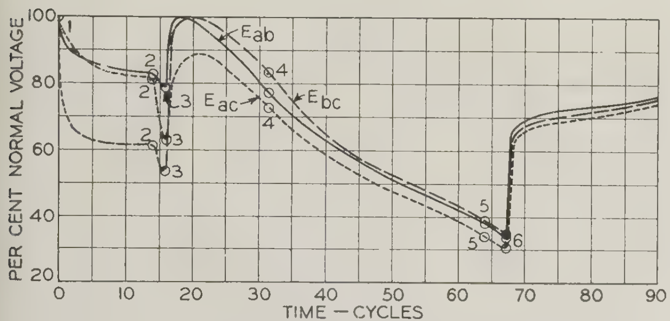


Fig. 5. Curves obtained from oscillogram 11 showing deviation of bus voltage from normal 440 volts during a single-phase-to-ground fault at Greenville substation

Designation of curves same as in figure 4

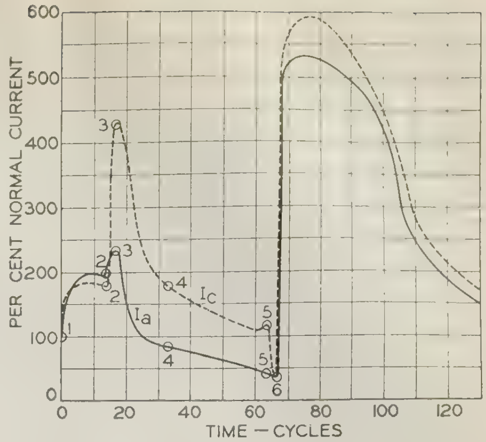
Preliminary Field Tests

Field tests were conducted in January 1936 to check the feasibility of the scheme of operation and the adequacy of the apparatus to produce the required results.

Figure 2 shows the results of deceleration tests on 700-horsepower and 1,800-horsepower synchronous motors driving pulp grinders. The motor speed at synchronism is 90 rpm. The curves indicate that for this type of drive the frequency change in the first 3 to 7 cycles after loss of supply source is ample to initiate relaying through a frequency-type relay.

Fig. 6. Curves obtained from oscillogram 11 showing current of 440-volt bus during a single-phase-to-ground fault at Greenville substation

Designation of curves same as in figure 4



Preliminary tests involving transmission and plant equipment were made without resorting to actual short circuits on the 110-kv system. Thus the variable of arc extinction was removed and it was possible to picture completely the over-all switching performance and to determine the time of operation of the component parts of the switching cycle. The tripping and automatic reclosing cycle was initiated through the use of the carrier-current relaying apparatus. The trip relay contacts were closed manually but actual tripping was prevented by the presence of carrier over the line. A momentary suppression of carrier gave simultaneous tripping to the Sterlington and Indianola breakers.

Figure 3 shows the magnitude and direction of power flow on the 2,300 and 440 volt busses in the plant. The first operation was recorded on oscillogram 8, in which the time delay adjustment was set to secure reclosure of the order of one second. In the second test all time delay was taken out of the reclosing cycle to secure the minimum possible time for reclosure. The data from these oscillograms are of interest in that they give a fairly complete picture of the variation in power exchange between the synchronous and induction units under different loadings of the plant and city of Greenville.

The records from oscillogram 7 show that the synchronous motors act as generators almost instantly after opening of the Sterlington breaker and before opening of the Indianola breaker. The instantaneous reversal may be the result of angular readjustments caused by change in power flow between systems upon opening of the Sterlington breaker, or because the load taken by the synchronous units is slightly pulsating due to possible hunting in the control system used to maintain hydraulic pressure on the rams used to press the logs against the grinders.

The power quantities as recorded in the 2 busses indicate clearly from data taken from oscillogram 7 that the synchronous units act as generators for a period of 11 cycles and supply energy to the induction motors, the line, and the city of Greenville. The combined shaft and electrical load causes rapid deceleration of the synchronous unit and at the end of $11^1/_2$ cycles the power reverses again, and the

induction motors acting as induction generators attempt to maintain the speed by supplying power into the synchronous units as well as carrying the line and Greenville load. The synchronous motor breakers were tripped in 17 cycles. Reclosure occurred in 52 cycles and normal speed of all induction motors was attained in from 70 to 80 cycles after reclosure.

The records taken from oscillogram 8 follow in general the same trend as indicated from oscillogram 7 except that for the first 10 cycles after opening the Sterlington breaker the power relationship between the 2 busses differs materially, indicating considerable difference in the shaft loading, line conditions, and Greenville load at the instant the Sterlington breaker opened. It is to be noticed that the synchronous-motor power did not reverse until the Indianola breaker opened. With reclosure of the line breaker in 27 cycles after tripping, the induction motors came back to normal speed in approximately 16 cycles after reclosure.

The facts disclosed from these 2 oscillograms indicated clearly that the line capacitance was an important factor in causing the induction motors to be excited from the line and hold up the voltage on the 110-kv side after the synchronous motors had been switched out. It was thought that when actual arcs appeared on the line it would not be possible to reclose in the minimum relaying time of $27^1/_2$ plus 6 cycles or from 33 to 34 cycles indicated as physically possible from oscillogram 8, but that time delay must be introduced to assure arc extinction.

Field Tests With Faults on the 110-Kv System

To determine the effect of primary short circuits on over-all performance a series of faults were placed on the 110-kv system, which incidentally gave a complete check on the performance and connections of the carrier-current relaying system. A total of 19 faults were initiated both inside and outside the protected zone.

The faults were placed on the system at points of minimum line insulation where the arc would play over a minimum spacing in air. Fine copper wire was wrapped across arcing rings and the fault was applied by manually closing an air-break switch. It was thought that the presence of copper vapor in the arc and minimum clearances would represent the worst type of arcing conditions to be expected and undoubtedly would be more severe than the majority of arcing conditions that would occur on the line proper, where greater clearances involving wood are encountered.

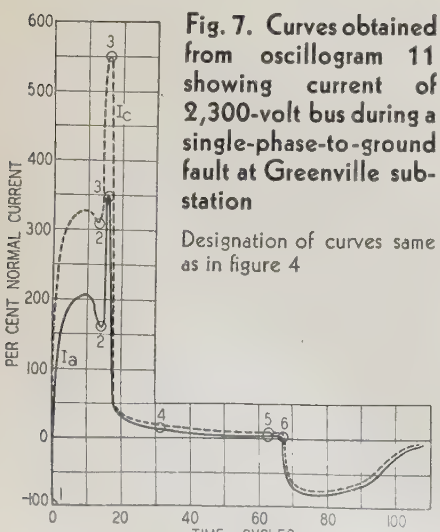
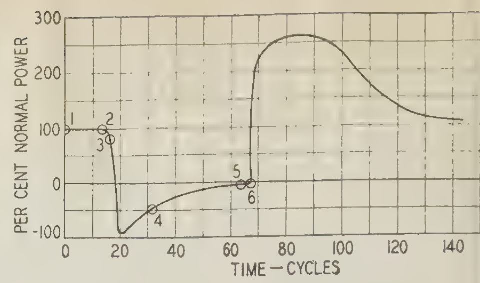


Fig. 7. Curves obtained from oscillogram 11 showing current of 2,300-volt bus during a single-phase-to-ground fault at Greenville substation

Designation of curves same as in figure 4



Designation of curves same as in figure 4

Fig. 8. Curve obtained from oscillogram 11 showing 3-phase power of 440-volt bus during a single-phase-to-ground fault at Greenville substation

To illustrate the over-all performance, the results of tests with single-phase-to-ground and phase-to-phase-to-ground faults at the Greenville substation are presented.

Figure 4 shows the frequency recorded in the U.S. Gypsum plant during the fault condition and up to reclosure. The fault occurred at time zero. The Sterlington breaker opened after 14 cycles, and the Indianola breaker opened, 2 cycles later. The frequency dropped rapidly and was at approximately 80 per cent normal in $31^1/_2$ cycles when the synchronous-motor breakers were opened. At this point the frequency is determined by the relationship between induction-motor and transmission-line characteristics. At point 5 the arc was extinguished and reclosure occurred at $67^1/_2$ cycles after the inception of the fault. Figures 5 to 8 inclusive show the voltages, currents, and power into and from the 2,300 and 440 volt busses in the plant.

Figures 9 to 13 inclusive show similar relationships for a phase-to-phase-to-ground fault at Greenville substation. The Sterlington breaker opened in 12 cycles, followed $2^1/_2$ cycles later by the Indianola breaker. The synchronous units were tripped in $32^1/_2$ cycles. The arc was cleared on one conductor in 40 cycles and the second arc was cleared in 57 cycles. Reclosure occurred at 66 cycles.

Plant Operation During Switching Cycle

The plant apparatus in general performed in a manner to be expected when subjected to a switching cycle as outlined previously.

Two synchronous motors used to drive kiln fans are essential to the continuous operation of the plant. Arrangements were made to disconnect these motors from the line and to restart them automatically upon return of normal voltage. All other synchronous motors were to be restarted at the convenience of the plant operators.

Summary of Results

1. For the particular plant under consideration it was demonstrated that in case of a fault on the high-voltage supply line, the line could be disconnected from the generating source for a period in excess of

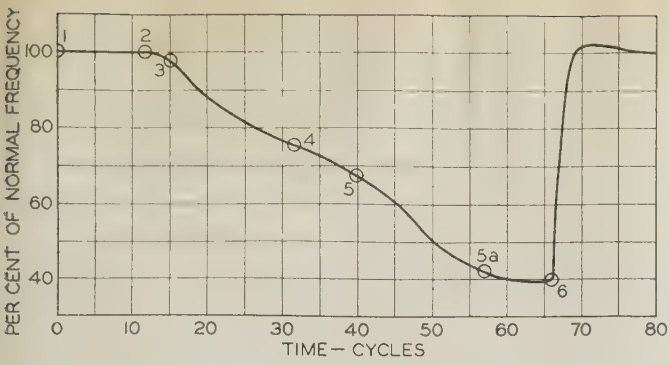


Fig. 9. Curve obtained from oscillogram 12B showing deviation of frequency from normal 60 cycles during a phase-to-phase-to-ground fault at Greenville substation

Designation of curves same as in figure 4

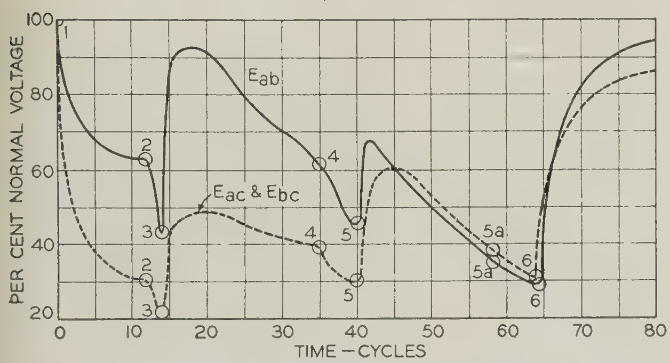


Fig. 10. Curves obtained from oscillogram 12 showing deviation of bus voltage from normal 440 volts during a phase-to-phase-to-ground fault at Greenville substation

Designation of curves same as in figure 4

one second and reclosed without disorganizing co-ordinated drives within the plant.

2. The presence of the long high-capacity transmission line provides the necessary source to excite the induction motors and thus hold up the voltage on the line when it is disconnected from all synchronous sources. This retards arc extinction and thus increases the necessary time to complete the reclosing cycle.

3. In future applications it may be possible to decrease the time of reclosure by opening the supply breakers to the individual plants, thus de-energizing the supply line and extinguishing the arc more rapidly. Such procedure will increase the cost of installation and complicate the control, as higher-speed reclosing breakers will be needed at the individual plants.

4. Because of difficulty in measurements, etc., it was impossible, at the time, to make voltage measurements at the point of fault to collect additional data on arc extinction with partial voltage across the arc.

5. The series of tests indicate clearly that rapid reclosing of high-voltage breakers is practical and that a single-circuit high-voltage power supply to certain types of co-ordinated drives and processes can be made to be essentially free from the effects of lightning and furnish practically uninterrupted service when considered from a production standpoint.

Operating Experience

The operating experience in the field has covered 13 operations between the dates of June 25 and August 8, 1936. Eleven automatic reclosures were successfully completed. In 2 instances the Sterlington breaker failed to reclose. The first failure to reclose was caused by the presence of foreign material around the plunger of an auxiliary relay which caused it to drop out sluggishly after the trip current had been interrupted by the auxiliary switch on the oil circuit breaker. The cause of the second failure to reclose is unknown as the equipment functioned an hour later in a normal manner. Subsequent tests failed to disclose the cause of the second failure. It is interesting to note that careful records taken on this line for the 13 operations recorded disclose that 5 faults were of the 3-phase type whereas 2 others involved 2 conductors and ground.

Part II—Carrier Current Relaying and Breaker Reclosing Control for the Sterlington-Indianola Line

To meet the general requirements for relaying and reclosing apparatus as outlined earlier in the paper, an improved relaying and breaker control is required to meet the following conditions of operation:

1. Simultaneous tripping of the breakers at both ends of the line for all faults within the protected section.

2. The relay time to be of the order of 6 cycles maximum so that over-all breaker tripping time does not exceed 12 or 14 cycles.

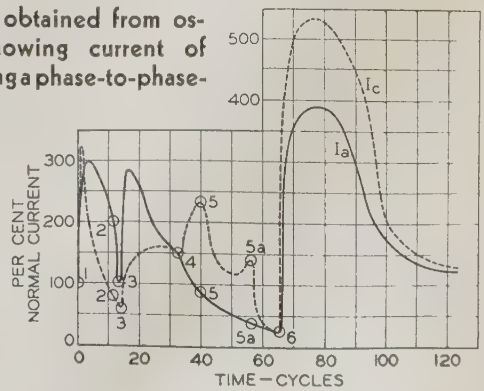
3. The breaker reclosing control apparatus to be arranged so that the reclosing time can be controlled readily from a minimum time restrained only by existing physical mechanical limits to a maximum of 3 seconds. The reclosing cycle is to be locked out in event a second relay operation and breaker opening occurs at any time within 3 seconds maximum after the original fault. At the expiration of the timing cycle of 3 seconds the control scheme is to reset and be in position to again repeat the reclosing operation.

Figure 14 shows the system connections, current values, power relationships, etc., available at various points on the Sterlington-Indianola line that determine the selection and limits under which the relays will have to operate. The 110-kv circuit neutral is grounded at Sterlington but not at Indianola as the step-down transformers are delta connected on the high-voltage side. Thus the zero-phase-sequence current passing Indianola is a function of grounding conditions at other points outside the zone to be protected.

This relay application is considered to be of interest because of the wide range of operating requirements to be met and because, to the authors' best knowledge, the 120-mile 110-kv line section in-

Fig. 11. Curves obtained from oscillogram 12 showing current of 440-volt bus during a phase-to-phase-to-ground fault at Greenville substation

Designation of curves same as in figure 4



volved is the longest on which carrier-current relay equipment has been used.

Variation in Fault Currents

From a-c calculating board studies the fault currents at various locations throughout the line section for which the relays must operate were available. Figure 14 includes the more important values.

The phase relays at Sterlington must carry load currents including swings of 200 amperes, yet must block tripping (for faults on the bus side of the breaker) under minimum fault conditions when the current is also 200 amperes.

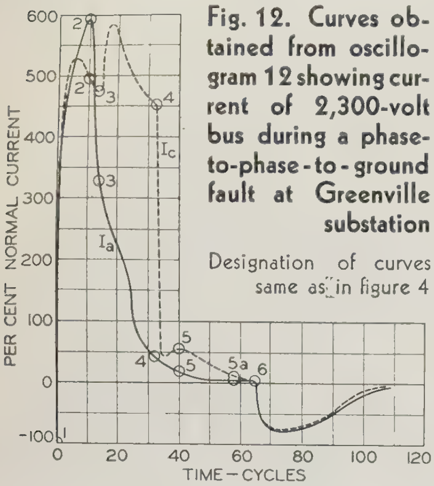


Fig. 12. Curves obtained from oscillogram 12 showing current of 2,300-volt bus during a phase-to-phase-to-ground fault at Greenville substation

Designation of curves same as in figure 4

The phase tripping current at Sterlington varies from 3,550 amperes maximum for faults near Sterlington, to approximately 450 amperes for faults at Indianola. The phase current from Indianola varies from 200 amperes minimum for faults at Sterlington to 730 amperes for faults near the Indianola bus. Thus, for faults in the section under discussion, the relays have ample margin for distinguishing between load and fault currents. However, for faults external to that section, where relays at the end nearest the fault must initiate carrier, resulting fault currents flowing in one direction may be less than load currents flowing in the reverse direction.

The current supplied from Sterlington for ground faults near Sterlington is 4,400 amperes compared with 50 amperes from Indianola. Indianola is not a ground source, hence lower ground currents are available at that station.

The fault currents supplied from each end for low-tension faults at Greenville might cause unnecessary tripping. This is true only for faults near the substation; 13.2-kv faults a mile or more from the substation produce lower currents than any fault on the high-tension system. It was decided not to install carrier-transmitting equipment for Greenville to block tripping for Greenville low-tension faults as statistics indicated practically no past difficulties from such faults and the increment in expense for added protection could not be justified.

Relays Selected

The intermittent-carrier-type relaying system using instantaneous-overcurrent phase starting and tripping relays in combination with a polyphase power-directional relay was selected. Separate relays were used for ground fault protection. For phase faults the time delay necessary to permit the initiation and reception of carrier was supplied through the use of a definite time auxiliary relay.

Induction-type overcurrent relays have been used in the past, their inherent time delay being used to provide necessary co-ordination. However, the variation in relay timing with fault location would be greater with such relays and it was doubtful if high-speed clearing could be obtained when minimum fault currents exceed the relay setting by only 40 per cent.

For the range of currents available the instantaneous-type relays selected offered the following advantages:

1. The timing sequence is largely independent of fault magnitude. (The instantaneous relays operate within 2 cycles at pick-up value.)
2. Simultaneous tripping could be closely realized.
3. Instantaneous relays could be set for fault currents closer to load-current values.
4. Better speed could be obtained for low relay-operating currents.

The resulting simple and direct relaying and carrier connections are illustrated in figure 15.

For phase faults within the line section the tripping sequence is as follows:

The phase tripping relays operate on the affected phases, permitting the time-delay relay to energize as the *b* contacts of the tripping relays open. At the expiration of the time delay (3 cycles), the trip circuit is completed through the *a* contact of the tripping relays and the time-delay relay, and through the *b* contact of the receiver relay. The action is the same at both stations. The polyphase directional relay is free at all times to follow the fault or load current and will open the right-hand contact for internal faults. Although the carrier-starting overcurrent relays are also operated, carrier is not sent because the directional contact is open, and blocking does not occur.

Should the fault be external to the section indicated in figure 14, the polyphase directional relay will close its right contact and complete the plate circuit to the transmitter, initiating carrier. Carrier received at both terminals prevents the completion of the trip circuit.

It is evident that for successful operation the starting and polyphase directional relays must operate before the time-delay relay can complete the trip circuit. With a fast receiver relay this

Designation of curves same as in figure 4

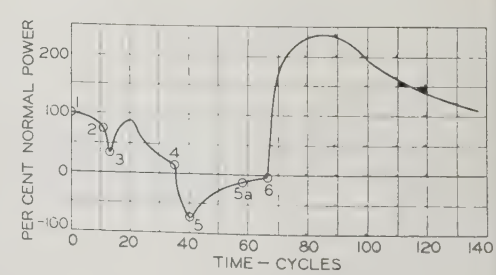


Fig. 13. Curve obtained from oscillogram 12 showing 3-phase power of 440-volt bus during a phase-to-phase-to-ground fault at Greenville substation

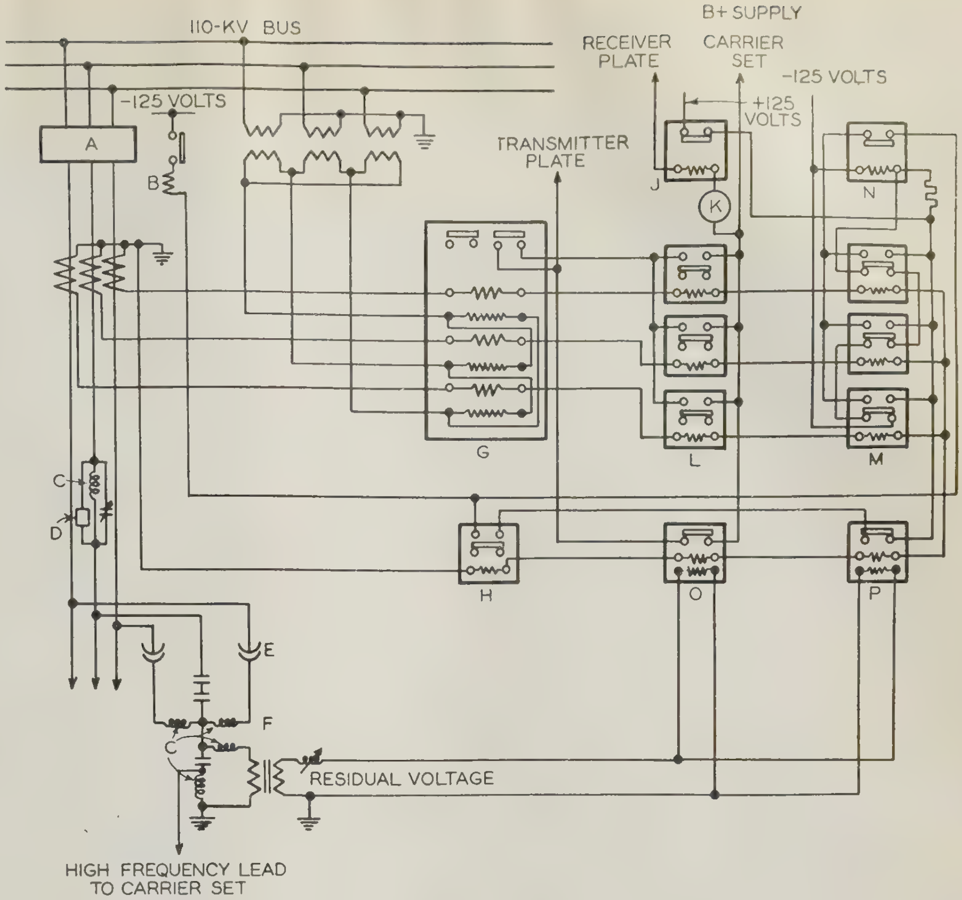


Fig. 15. Diagram of connections of carrier-current relays

A—Oil circuit breakers
B—Trip coil
C—High-frequency choke coil
D—Lightning arrester
E—Cable-type capacitors
F—Pedestal-type coupling-capacitor potential device
G—Polyphase directional relay
H—Ground overcurrent relay
J—Receiver relay
K—Ammeter
L—Phase overcurrent starting relays
M—Phase overcurrent tripping relays
N—Time-delay closing relay
O—Ground directional starting relay
P—Ground directional tripping relay

time interval can be small, as the overcurrent and directional relay operate concurrently.

The wide variations in residual current and voltage prohibited the use of the time-delay pick-up relay for ground faults. No ground-directional relay having sufficiently constant speed under the varying residual power conditions was available. Consequently, 2 directional relays, one for starting and one for tripping, were used, co-ordination in timing being accomplished between the tripping relay at one end and the starting relay at the other through lever setting and damping magnets of the induction-disc directional relays. Each relay is set for its individual requirements and because co-ordination with load value was not required, ample margin existed.

The ground relays function as follows:

1. For internal faults, the ground directional tripping relays at each end operate, closing their front contacts after a delay and completing the trip circuit through the ground overcurrent and receiver relays.

2. For external faults the carrier starting relay nearest the fault operates to send carrier directly. (Note the starting and tripping ground directional relays are polarized and connected to close contacts for opposite direction of power flow.)

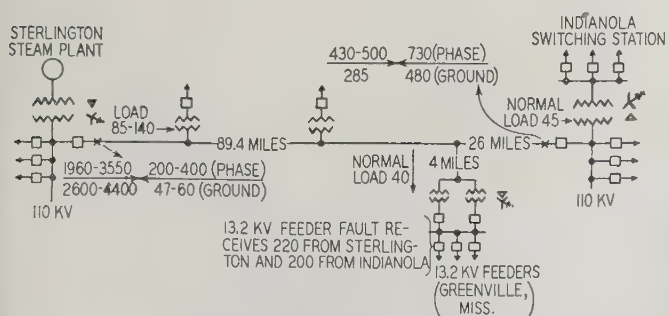


Fig. 14. Single-line diagram of 110-kv transmission system supplying Greenville, indicating load and fault currents in amperes

A push button permits transmission of carrier for test purposes. Such tests do not interfere with tripping under fault conditions, as contacts on the starting overcurrent relay on each phase and on the ground overcurrent relay (not shown in the figure) open the push-button circuit. The phase starting relays at Sterlington, set to operate for minimum faults of 140 amperes, must carry load currents of greater values and therefore have their coils short-circuited by an auxiliary relay energized from the tripping contact of the polyphase directional relay. Since the normal power flow is toward Indianola, the starting relay coils are normally short-circuited. These circuits are not included in figure 15.

The reclosing and lock-out circuits for the Sterlington breaker are shown in figure 16. The operation of the circuit is as follows:

With all relays de-energized the tripping impulse actuates a contactor switch to energize the set-up relay, one contact of which seals the initiating contact. A second contact energizes a synchronous timing relay having 2 adjustable contacts. One is a passing or momentary contact, while the other is closed at the expiration of the timing. The first is used for initiating reclosure and the second for restoring the reclosing circuit to normal. The closing of the first timer contact energizes an auxiliary closing relay through a contact of the set-up relay. The auxiliary relay, on closing, energizes the breaker closing relay and solenoid. The closing circuit is interrupted by the breaker auxiliary switch but the auxiliary relay remains energized until the total time expires, thus insuring only the one closing attempt

within the 3-second period and preventing breaker "pumping." If the breaker remains closed the final timer contact restores all relays to normal by dropping out the set-up relay. Should the breaker reclose on a fault, only the one closing attempt is made. The timing adjustments permit reclosure in from 6 to 180 cycles.

It should be mentioned here that the Indianola operator can reclose that breaker after each fault. The operating instructions require a closure one minute after tripping, resynchronizing if necessary.

Equipment Supplied

The relays for each station were supplied on conventional switchboard panels, shown in figure 17. At both locations these panels constitute a portion of an entire new switchboard. Only the carrier relays were required, existing metering and control panels being used. The conventional relays (overcurrent and directional overcurrent) were retained as back-up protection.

Residual potential for polarizing the ground relays was available at Indianola from an existing residual-voltage capacitor potential device. Two cable-type capacitors were available at Sterlington. A new coupling capacitor potential device was supplied for the third phase. This unit included a common neutral capacitor for all 3 phases. High-frequency choke coils in the various leads prevented loss in carrier energy in the unused phases. These connections are indicated in figure 16. Phase-to-ground coupling was used for the carrier sets. A separate coupling capacitor was installed at Indianola for the carrier connection.

Conventional resonant choke coils or wave-traps were used, mounted in a rather novel but effective manner as shown in figure 18. The pedestal coupling capacitors were mounted on a raised rectangular structure. The choke coil was mounted horizontally, one end supported by the cap of the pedestal capacitor, the other end by insulators extending from a vertical pipe. Standard conduit bends, with flanges bolted to the choke coil and the capacitor and insulator, support the choke coil assembly. The height of the structure permits direct choke-coil connections without disturbing bus or riser alignments.

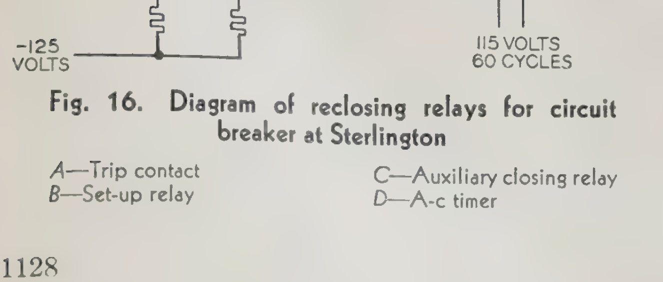


Fig. 16. Diagram of reclosing relays for circuit breaker at Sterlington

A—Trip contact
B—Set-up relay
C—Auxiliary closing relay
D—A-c timer

Fig. 17. Relay panel

Fig. 18. Typical installation of carrier coupling apparatus

The carrier sets were furnished mounted in a small weather-proof steel housing. Each consists of 3 major elements. A tuning-inductance panel supplies the means of resonating the coupling capacitance to the desired frequency and serves to match the line impedance to the transmitter-receiver impedance. The transmitter uses 2 or 3 industrial-type tubes dependent upon output desired. One tube serves as an oscillator, and the other 1 or 2 as power amplifiers. Where output in excess of 12 watts is required 2 tubes are employed. Where not needed the second power-amplifier tube is omitted. A single-tube detector is used for the receiver. A base panel composed of a conventional rectifier tube, transformer, and filter supplies the various voltages required.

Power supply for the carrier sets is obtained from 250-watt rotary inverters operated from station batteries and changing 130 volts continuous to 115 volts alternating current. An auxiliary unit and automatic-change-over panel insures continuity of supply and permits maintenance.

Factory and Installation Tests

The relaying and carrier apparatus was set up in the manufacturer's laboratory for preliminary coordination and adjustment tests. The relays were

connected to an equivalent testing transmission system, and were operated at the same current values as on the actual system. Over 300 test operations were made and proved the correct co-ordination of design and application. The relaying time varied from $3^1/_2$ to 6 cycles for faults at various locations and with different system conditions.

Before field testing, each overcurrent relay and current transformer was calibrated for the desired setting by circulating primary current through each breaker pole.

After installation, joint collaborative tests were made in the field under the direction of the utility's and manufacturer's engineers. Faults were applied at Sterlington and Indianola, both inside and external to the protected section, and at Greenville. A total of 19 faults was placed on the system to check all possible limiting conditions of operation. The majority of the faults were required to determine plant rather than relay characteristics.

In each instance the relaying performed correctly without readjustment or changes.

This installation represents a new use for carrier-current equipment—the combining of carrier relaying with high-speed reclosure—and no doubt will result in other installations as demanded by service and economic requirements. The success of the apparatus in fulfilling the particularly difficult application requirements substantiates the value of the calculating board and testing laboratories in providing a better answer to application problems with a minimum amount of field testing and adjustment.

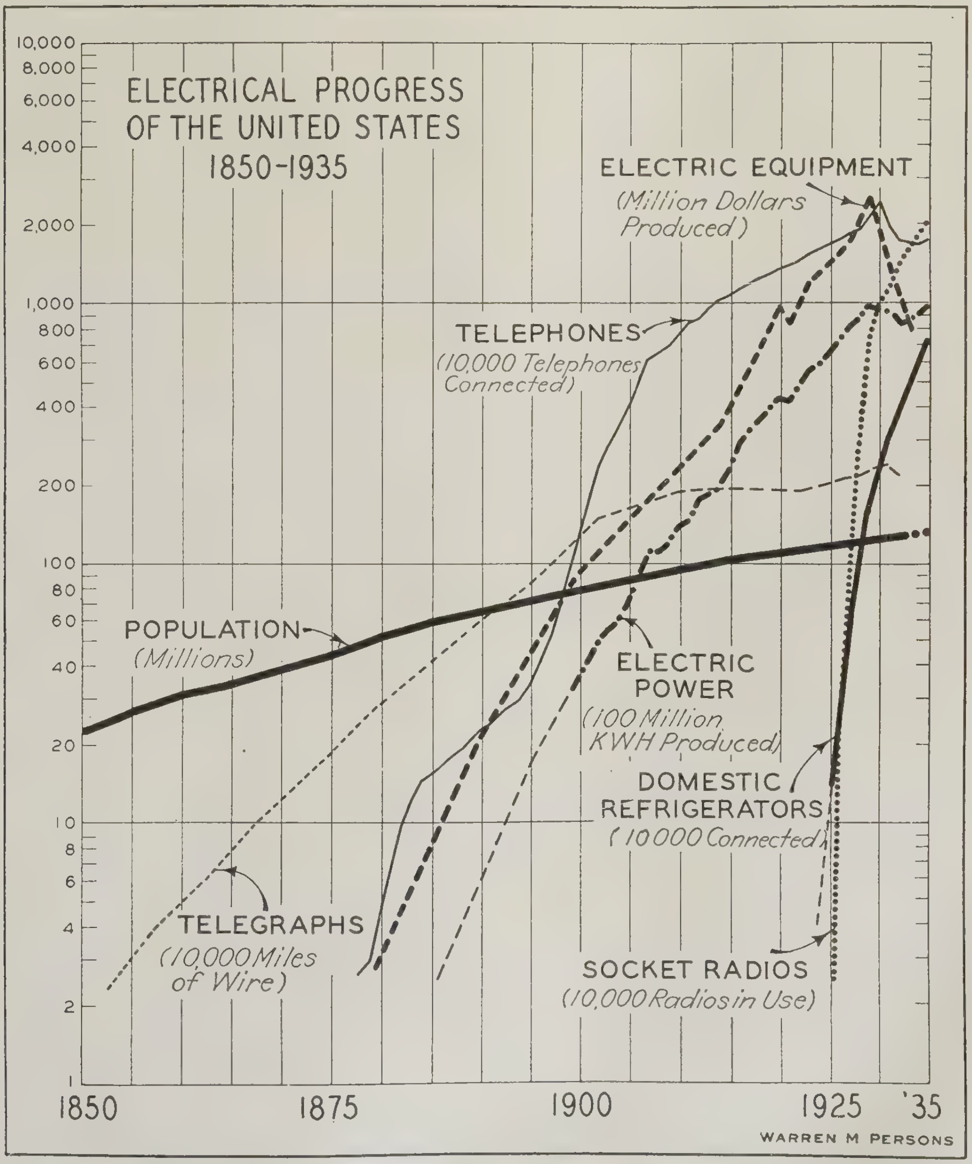


Chart showing electrical progress in the United States, prepared by the Temperature Research Foundation of the Kelvinator Corporation, New York, N. Y., from data collected from various industrial sources

Experiences With a Modern Relay System

A summary of practical operating experiences with a modern protective relay system over a 5-year period is given here, together with an analysis of significant results.

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In the past many papers have appeared in the technical press on the subject of power-system relay protection, particularly from the viewpoint of the application engineer. Few papers however, have described the performance of such relay equipment.

In the belief that greater knowledge may be gained by observing experiences, this paper has been prepared, its purpose being to describe the performance of modern high-speed relay equipment as applied to the circuits of the Union Electric Light & Power Company of Missouri. A diagram of the arrangement of these circuits is shown in figure 1, wherein is given a complete summary of the relay installation as it is at the present time.

Installation of this equipment in 1931 was made necessary by the construction of the Osage hydroelectric station which, being rather remote from its load center, required long transmission lines and introduced a stability problem of prime importance. From these experiences the limitations of the protective gear, at first considered quite adequate, were determined. These are described, as are also the improvements and additions required to make the system more versatile. It is hoped that the information contained herein will aid others, not only in the application of new relay installations, but in improving the performance of existing systems, using the simplest types of high-speed relay schemes of proven soundness and economy.

Conclusions

Analysis of the experience data given in this paper leads to the following conclusions concerning modern high-speed relay systems:

1. Automatic recording devices are essential to a proper understanding of the performance of a high-speed relay system. It has been demonstrated that they will determine: (a) type of fault and phases involved, (b) location of fault, (c) fault isolation time, (d) magnitude of current and voltage, (e) sequence of relay and switch operations, (f) causes of incorrect relay operation, and (g) empirical formulae to determine switching speeds necessary to preserve system stability. In addition, automatic recording devices are of great assistance in guiding the improvement and extension of the relay system. Data obtained also have been of material benefit to manufacturers in assisting them to determine proper design constants of certain items of protective equipment.

2. The reduction of relay operating time, considered apart from oil-switch operating time, cannot be carried beyond a certain minimum. Experience shows that in certain specific applications relay operating times of the order of one cycle or less may result in unreliable performance. The application engineer can readily recognize these proposed installations wherein the minimum relay operating time should be carefully determined.

3. Most faults on grounded-neutral transmission systems are initiated between ground and one conductor. Therefore greatest consideration should be given to the application of relay systems operating on zero-phase-sequence quantities. It appears probable that in the past, phase protection has been overstressed in importance. In some instances phase relays may be entirely eliminated.

4. By the application of high-speed relays and oil circuit breakers the stability of power systems can be materially improved, approaching a point where the transient stability attains equality with the static stability limits. This procedure is more economical and more positive in action than schemes that utilize mechanical devices designed to reduce fault current and to maintain voltage, or that rearrange system interconnections. It is highly important that proper consideration be given to the relaying of the secondary transmission system. In some instances on the Union system, faults of secondary origin have resulted in the trip-out of high-voltage transmission circuits, because of unstable conditions caused by the fault.

5. It has been forcibly shown that an extensive protective system cannot be installed once and for all and then expected to function perfectly under all circumstances. The protection engineer must constantly be alert, watching for incorrect or doubtful operations, and must be ready to remove obsolete equipment and install new equipment of approved design. Long experience invariably will demonstrate that the original installation is inadequate to comply with advanced conceptions of desirable relay performance and will point the way to necessary additions and improvements. In every year from 1931 to the present time, changes have been made on this company's protective system. Modern relays and circuit breakers have been installed in place of those of earlier designs, and numerous other additions and improvements have been effected with the result that instability and incorrect relay operations now are quite remote.

Recording Instruments

Automatic quick-trip roll-type instruments, capable of making records of voltage, current, and frequency during system disturbances, have been available for many years. They are limited however in their speed of initiation and in their inability to give true records of the behavior of voltages and currents during faults. With modern methods of high-speed fault clearing, the automatic oscillograph is probably the only instrument capable of giving accurate information for intelligent study of apparatus and system performance. When this oscillograph properly connected into transmission circuits, records obtained will show at a glance the type of fault and the phases involved. They show the time required to clear a fault, the magnitude of current and voltage in the several phases, and the sequence of relay and switch operations.

Transmission line faults now are cleared in 0.1 second or less. With such speeds, flashovers of line insulators leave little evidence to aid patrol crews in

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locating damaged material. Although the damage in most cases is slight and immediate replacement is not necessary to permit normal operation of the line, the location should be known and replacements made as soon as possible. It has been demonstrated that the information supplied by the automatic oscillograph will make possible the determination of the fault location with an error of less than 5 per cent of the total circuit length. A recent experience may serve to illustrate this point more forcibly.

An automatic oscillograph is located at the 66-kv substation at Venice, Illinois, connected to record ground current in the interconnecting circuits to the Page Avenue and Cahokia stations. Several radial 66-kv feeders emanate from this station, supplying several large load centers. A fault that occurred on one of these circuits was isolated by the instantaneous ground relay in 8 cycles (60-cycle basis) as was shown by the oscillographic record. Line crews made an immediate patrol of the 17-mile circuit, but were unable to find evidence of any damaged equipment. Later the oscillograph record was analyzed, and from the value of ground current it was determined, by reference to previously calculated curves, that the fault occurred on the number 2 phase 4.75 miles from the Venice station. A second and more detailed inspection, made by climbing the towers, in this vicinity, revealed that 6 insulator units on the number 2 phase had flashed over at a point 3,000 feet from the indicated location. The error in the oscillograph determination was less than 4 per cent of the total line length. It is important to note that the damage done to the 6 insulator units was severe enough to require their replacement, and further, that this condition could not be observed by the regular ground patrol.

The oscillogram shown in figure 2 is a good example of the wealth of information that may be obtained from a single record. Emanating from the Venice station are 2 66-kv circuits supplying power to the Staunton 66-kv switching station. At an intermediate point taps are taken off both lines to supply the 66-kv bus at the Stallings switching station. During a lightning storm on February 26, 1936, relays on both circuits operated and breakers opened on both lines at Venice and Staunton and on one line at Stallings. The oscillographic record shows that the fault first involved the number 1 phase of the number 1 line causing relays on it at Venice to operate after an interval of 22 cycles and at Stallings after an interval of 24 cycles. These 2 points are clearly indicated on the record. At this same instant the number 3 phase of the number 1 line also became involved causing the number 3 phase reverse-power relay on the number 1 line at Staunton to operate. Before this cleared, however, the number 1 phase of number 2 line was involved in the flashover. This point is shown clearly by the sudden increase in ground current in the supply circuits to Venice. If the impedance of the fault to ground on the 1 and 3 phases of number 1 line was rather high, the resulting current distribution readily could cause tripping impulses to be given to the reverse-power relays on both lines at Staunton. This undoubtedly did occur, causing them to operate as described. The number 2 line at Venice, of course, received its tripping impulse at the moment the arc involved this line, and cleared after a total time delay of 61 cycles.

The current values indicated that the fault took place at a point 7.65 miles from Venice. This information was given to the line department, which found burns on the ground wire and structure of a tower 7.59 miles from the Venice Station. Thus, practically every detail of the fault was revealed from the oscillographic record.

The information supplied by the oscillograph in the 2 instances mentioned is typical of many other cases of trouble. In the past, little was known of the events occurring during a circuit trip-out, but today all details are revealed completely and little effort is required to keep in close touch with the performance of the protective system. At the present time, oscillographs are located at Venice, Cahokia, and Rivermines stations, in each case connected to record ground current and 1 or 2 of the phase-to-neutral high-voltage bus potentials. Initiation is also by means of ground current.

Location of the instruments is such that at least one automatic record will be obtained for a fault at any point on the 66- or 132-kv 60-cycle system, with the exception of the circuit between Osage and Page. A fourth oscillograph is to be installed at Page Avenue in the near furture to eliminate this deficiency.

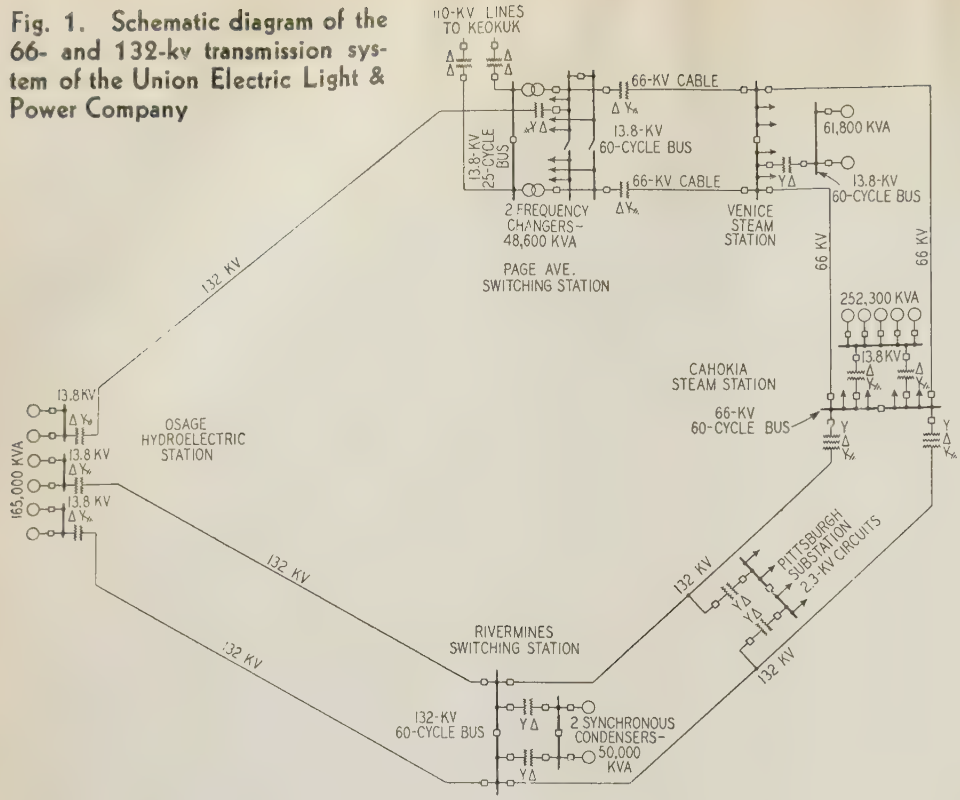
Limitation of Relay Speed

Within the last 6 or 7 years quite a change has taken place in the practices of transmission-system relay protection. Formerly, relay timing of the order of one second was adequate to isolate faults satisfactorily on the quite-stable systems supplying power only to local load centers. Today, systems are extensively interconnected, and great distances separate generating stations from their load areas. This has introduced a stability problem of great importance which has been solved predominantly by the application of high-speed relay and switching equipment. With 6- to 8-cycle breakers commonly available and relays capable of operating in less than one cycle, systems can be loaded to a point closely approaching their static stability limits.

But the question often arises: Can ultra-high-speed relays (one cycle or less) properly determine current and voltage conditions during the first cycle of a fault and give a correct operating impulse? If there exists during the first cycle a transient current, having a wave form and a phase relation unknown with respect to the reference voltage of the system, correct relaying is not assured under all conditions. A system disturbance that occurred during February 1936 may well be taken to illustrate this phenomena.

In figure 3 is shown a copy of an oscillograph record showing the behavior of ground-fault currents on the 66-kv system during a bus fault at the Cahokia substation. The fault was caused by the failure of a 66-kv bushing on one of the number 2 bus-section oil switches. The high-speed bus differential re-

Fig. 1. Schematic diagram of the 66- and 132-kv transmission system of the Union Electric Light & Power Company



NOTE: In tabulation below, all relays for line-ground fault protection are connected into the current-transformer neutral wires

Location	Line	Parallel-Line Protection L-L & ϕ	Parallel-Line Protection L-G	Single-Line Protection L-L & ϕ	Single-Line Protection L-G	Back-Up Protection
Osage	Rivermines		Balanced instantaneous overcurrent	Directional reactance	Time-delay directional overcurrent	Time-delay overcurrent
Osage	Page			Directional impedance	Instantaneous overcurrent	Time-delay overcurrent
Rivermines	Osage	Directional impedance	Instantaneous directional overcurrent	Same as parallel line protection	Same as parallel line protection	Time-delay overcurrent
Rivermines	Cahokia	Directional impendance	Instantaneous directional overcurrent	Same as parallel line protection	Same as parallel line protection	Time-delay overcurrent
Cahokia	Rivermines	Directional reactance	Balanced overcurrent	Same as parallel line protection	Time-delay directional overcurrent	Time-delay overcurrent
Cahokia	Venice	Balanced current	Balanced current	Directional reactance	Time-delay directional overcurrent	Time-delay overcurrent
Cahokia	Belleville	Balanced current	Balanced current	Non-directional impedance	Instantaneous overcurrent	Time-delay overcurrent
Cahokia	66-Kv Bus	Differential network on each bus section, connected into neutral current circuits of each line, and operative only on line-2-ground faults. Isolates only faulty bus section.				
Venice	Cahokia	Balanced current	Balanced current	Directional reactance	Time-delay directional overcurrent	Time-delay overcurrent
Venice	Page	Each circuit consists of 3 single-conductor cables			Instantaneous directional overcurrent	Time-delay overcurrent
Venice	Stallings	Balanced current	Instantaneous overcurrent	Non-directional impedance	Same as parallel line protection	Time-delay overcurrent
Venice	Alton	Balanced current	Instantaneous overcurrent	Non-directional impedance	Same as parallel protection	Time-delay overcurrent
Venice	66-Kv Bus	Differential network, similar to Cahokia 66-kv bus protection described above.				
Page	Venice		Balanced overcurrent		Time-delay directional overcurrent	Time-delay overcurrent
Page	Osage			Directional impedance	Instantaneous overcurrent	Time-delay overcurrent

lays operated properly, disconnecting all number 2 bus-section switches with very little disturbance to the system. For the type of fault experienced here the operation of the differential equipment was in itself sufficient to isolate it, but in addition the other Cahokia-Venice line was tripped by its balanced relays, apparently an incorrect operation, resulting in the separation of the system.

Referring to the oscillographic record it may be noted that during the first 7 cycles of fault the 2 Cahokia-Venice lines were supplying approximately1,000 amperes each to the bus fault at Cahokia. At the expiration of that interval the 66-kv bus tie switch at Cahokia was tripped by the differential protection. This resulted in a redistribution of fault current in the Cahokia-Venice lines. Normally it would be expected that the current supplied by the number 1 line would simply reverse its direction and, combining with the current supplied by the Page Avenue station, result in a heavy unbalance in the number 2 line direct to the fault, causing the number 2 line balanced ground relay to operate. This it did, but during the time that the number 1 line current was undergoing reversal (shifting phase angle by 180 degrees) it actually exceeded for a fraction of a cycle the value of current in the number 2 line. The record clearly shows 1,400 amperes in the number 1 line and 700 amperes in the number 2 line at this instant. Since the balanced relays operate in less than a half-cycle, this unbalance was of sufficient magnitude and persistance to cause them to operate to trip the number 1 line as previously recorded. At the completion of this reversal process of about

1-cycle duration, the currents became normal, 1,070 amperes in the number 1 line and 2,390 in the number 2 line. This unbalance properly caused the operation of the number 2 line balanced relays. Both circuits were tripped in this manner.

It is apparent from the foregoing description that the balanced relays, operating in less than a half-cycle are too fast to "ride through" properly the transients that exist on a system during switching surges that occur while faults are in the process of being isolated. It is not to be implied that all transients or surges will cause such incorrect operation. The application of very quick-acting balanced relays to parallel line protection of circuits interconnecting 2 power sources provides probably the most likely situation wherein such incorrect relaying may occur.

Frequency of Various Types of Faults; Relays for Primary Protection

The company's major transmission system, referring again to figure 1, consists of 641 circuit-miles of 66- and 132-kv, 60-cycle circuits. On the 132-kv system there are 492 miles of circuit interconnecting Osaga with Cahokia by way of Rivermines over one right-of-way, and with Page Avenue over a second right-of-way. On the 66-kv system, 26 miles of circuit interconnect the Page Avenue, Venice, and Cahokia stations. The remaining 123 miles of 66-kv circuit supply several of the larger load centers from the Venice and Cahokia 66-kv busses.

The 132-kv circuits from Osage to Rivermines and to Page Avenue are probably unusual enough in characteristics to warrant some further description. Two of these circuits from Osage are carried to the Rivermines station, 120 miles distant, over a steel tower line fitted with hinged wooden cross-arms. The conductors are 250,000-circular-unit copper, vertically spaced 14 feet apart with a 3-foot horizontal offset. Insulation consists of eleven $5^3/_4$-inch insulator units. Two galvanized steel ground wires are carried 21 feet above the conductors. The remaining circuit from Osage, interconnecting with the Page Avenue station 136 miles distant, is a single-circuit line carried by a wood-pole H-frame structure. The conductors are 336,400-circular-unit steel-reinforced aluminum cable spaced 16 feet 4 inches horizontally and insulated with eleven $5^3/_4$-inch insulator units. Two ground wires are carried 10 feet above the conductors.

The remaining 66- and 132-kv transmission lines are of a normal steel-tower construction with no unusual features except that from 1 to 3 more insulator units per string are used than ordinarily is considered common practice.

Since 1931, at which time the installation of the high-speed relay system was effected, accurate records have been kept of disturbances occurring on this portion of the system. During these 5 years 106 faults resulting in the operation of relays on one or more 66- or 132-kv circuits have been recorded. It is quite significant to note that 99 of these (93 per cent) were initiated between one conductor and ground. In all cases where ground relays had been applied they cleared the circuit instantaneously and with minimum disturbance to the system. Considering the 132-kv system alone, the record is even more impressive: 39 faults were recorded and 38 of them (98 per cent) were ground faults. On the 66-kv system, 61 out of 67 faults (91 per cent) were initiated between conductor and ground. Although the percentage of ground faults on the 66-kv system is not quite so high as on the 132-kv system, it should be noted that on the 26-mile interconnecting circuits between Page Avenue, Venice, and Cahokia stations 14 faults have been recorded. Seven of these were on the 16 miles of underground single-conductor cable circuits and 7 on the 10 miles of 66-kv overhead circuits, all of which were cleared by the ground relay system.

Records similar to these are not peculiar to the Union system, and therefore it appears that greater consideration could well be given to the application of relays operating on zero-phase-sequence quantities.

Complete ground protection for a pair of circuits can be installed for a small fraction of the cost of comparable phase protection. Usually in instantaneous overcurrent relay in the ground circuit is adequate to provide all the protection necessary against phase-to-ground faults. The arrangement of the zero-phase network, of course, determines the type of protection to be applied. A high-voltage line, with delta-star grounded transformers at each end, interconnecting 2 low-voltage generator busses provides the ideal application for instantaneous non-directional ground relays. Radial feeders bussed at line voltage at the receiving end can be given instantaneous protection by means of high-current-setting overcurrent relays in the ground circuit. The relays are set with a current pick-up high enough to prevent operation during maximum generating conditions for a fault near the feeder and beyond and low enough to insure operation for

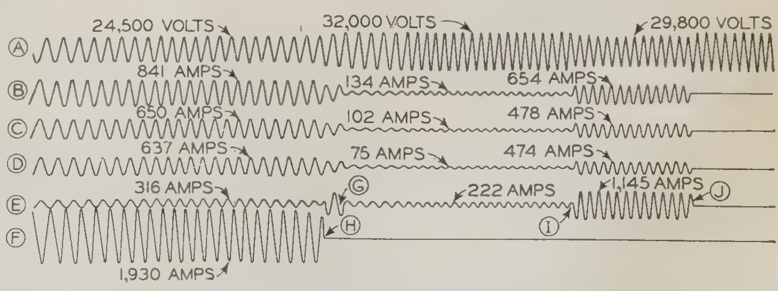


Fig. 2. Reproduction of an oscillographic record of a double circuit outage on Stallings 66-kv circuits

A—Voltage on phase number 1
B—Ground current on Venice-Page line number 1
C—Ground current on Cahokia-Venice line number 1
D—Ground current on Cahokia-Venice line number 2
E—Ground current on 66-kv bus tie
F—Ground current on Venice-Stallings line number 1
G—Venice-Stallings line number 1 opened at stallings by relays after 24 cycles
H—Venice-Stallings line number 1 opened at Venice by relays after 22 cycles
I—Fault involved phase number 1 of line number 2
J—Circuit number 2 cleared at Venice

faults near the plant bus even during minimum generating conditions. In the usual case, the great variation in ground current for a fault at the beginning of the line compared to a fault at the end of the line more than offsets variations in the impedance of the system to the bus being protected, and thereby insures sufficient current to operate the relays in a selective manner for a high percentage of the line length. Full line protection of radial feeders terminating in transformers at the receiving end does not require the high setting relays. In this application, no question of selectivity is involved and the relays may be set sufficiently low to be operative for any expected value of ground current, without regard to normal feeder loading.

Generating station interconnections, bussed at line voltage at one end and terminating in transformers at the other end may be protected simply at the bussed ends by instantaneous directional ground relays. At the transformer terminal high-current-setting overcurrent relays or the impedance ground relays are applicable.

Other circuit arrangements, of course, should be considered in view of the peculiarities of the arrangement, and relay applications made accordingly.

Although experience shows that ground relays can isolate more than 90 per cent of all transmission line faults, it is not be be construed that phase protection in general, should be eliminated or reduced to a mere fragment of what may be considered adequate today. Each circuit has characteristics of its own that require individual study. For instance, on the Union system the 66-kv tie circuits between the Venice and Page Avenue stations are underground single-conductor cables. Obviously, extensive phase protection of these circuits was unwarranted. Complete ground protection was applied with simple overcurrent relays acting as backup protection for phase-to-phase faults that might possibly occur on the terminal disconnecting equipment. Experience has shown that the application was correct, although to date the overcurrent relays have never been called upon to operate.

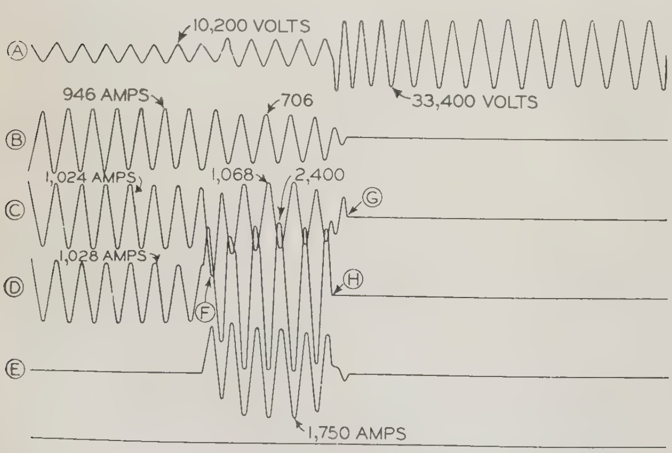


Fig. 3. Reproduction of an oscillographic record of a 66-kv bus fault at Cahokia

A—66-kv bus voltage on phase number 1
B—Ground current on Venice-Page line number 1
C—Ground current on Venice-Cahokia line number 1
D—Ground current on Venice-Cahokia line number 2
E—Ground current through 66-kv bus-tie breaker
F—Cahokia bus-tie breaker opened by relays, resulting in momentary current flow of 1,400 amperes in the Venice-Cahokia line number 1 as against only 700 amperes in line number 2
G—Cahokia-Venice line number 1 opened by relays
H—Cahokia-Venice line number 2 opened at Venice by relays

System operating experience seems to show that the most unusual types of faults occur between phases. In one instance, an airplane flew into a 66-kv line, causing the line balanced relays to operate. In another, gasoline from a broken pipe line under a 66-kv line burst into flames which involved the line; the line was cleared again by the balanced relays. Critical wind velocities, in conjunction with the formation of ice on the conductors of a 66-kv circuit caused the conductors to "dance" into contact with each other, resulting in several outages of the circuit.

Although faults between phases constitute only 7 per cent of the total number, it still is necessary to provide high-speed protection against them, but with greatest effort expended on the ground-relay system.

System Stability

Stability investigations made preliminary to construction and interconnection of the Osage hydroelectric station indicated that the system would not be immune to instability. Even though high-speed relays were to be installed throughout the major portion of the system, there still were several vulnerable locations, in which faults would not be isolated rapidly enough to prevent instability. At the time, it was not considered economically sound to apply high-speed protection at these points, and therefore the relatively slow-speed relays were left in service.

The first serious case of trouble occurred about a year after the interconnection was completed. On October 11, 1932, a 66-kv bushing on the main bus-tie oil switch at Venice station failed. At this time the bus differential protection had not been applied, and the fault was isolated after the long-time-delay overcurrent relays on the bus-tie breaker operated, followed by the operation of the balanced relays to open the lines at the Cahokia and Page Avenue stations. The opening of these circuits was sufficient to isolate the fault, but the severe shock to the system caused it to become unstable. The result was that the 132-kv tie circuits between Cahokia and Rivermines were tripped by the reactance relays at Cahokia and the Osage-Page 132-kv tie circuit was tripped at both ends by the impedance relays.

The conclusions arrived at as a result of this disturbance, and subsequent ones of a similar nature were: first, that power surges occurring after the clearing of a severe fault have a tendency to cause incorrect operation of relays of the distance type; second, that the most logical way to prevent excessive surges was to extend the high-speed relay system to protect all equipment the failure of which

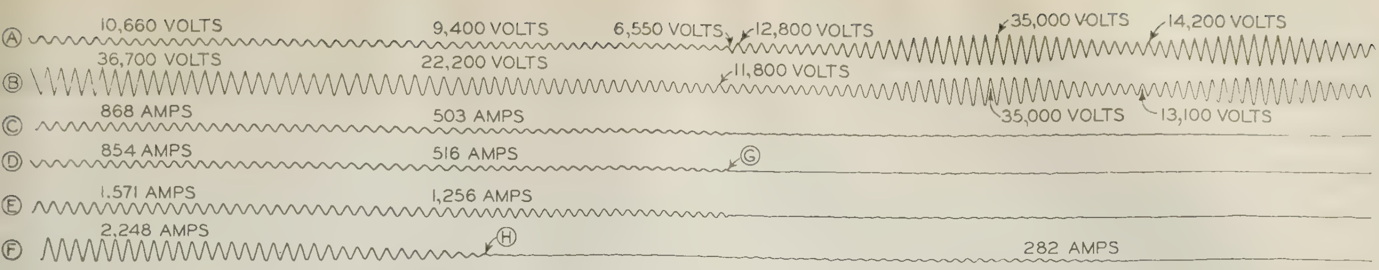


Fig. 4. Reproduction of an oscillographic record of currents and voltages at Venice station during system instability caused by ground fault on Venice-Stallings circuit

A—66-kv bus voltage, phase number 1 to neutral
B—66-kv bus voltage, phase number 3 to neutral
C—Ground current on Venice-Cahokia line number 1
D—Ground current on Venice-Cahokia line number 2
E—Ground current through 66-kv bus-tie breaker
F—Ground current on Venice-Stallings line number 1
G—Breaker on Venice-Stallings line number 2 opened at Venice after 56 cycles
H—Arc extinguished on Venice-Stallings line number 1 after 35 cycles

may result in loss of system stability. With these thoughts in mind, a plan was formulated and put into effect to remove those limitations of the relay system.

While this work, which was augmented continually by further experiences, was in progress several cases of instability occurred. Probably the most interesting one was caused during the late evening of Oct. 21, 1933 by a lightning flashover on the paired radial 66-kv circuits to Stallings out of the Venice station. Ordinarily the fault, which was within 2 miles of the station, would have been cleared rapidly by the line balanced relays with very little disturbance to the system, but in this instance the balanced relay on the faulted number 2 phase of number 2 line failed to operate, and the circuit was therefore cleared by the long-time-delay back-up overcurrent relays. The resulting disturbance to the system was so severe and of such long duration that the system became unstable, causing distance relay operations on the Cahokia-Rivermines and the Osage-Page tie circuits. Also, the Cahokia and Venice stations were separated by the operation of the reactance and balanced relays. Even though the system was separated into 4 distinct units, only 11 minutes was required to restore it to normal.

An automatic oscillograph record obtained from the Venice station provided a story of the events that took place during the disturbance. A copy of this record is shown in figure 4. The behavior of the ground current on the number 1 Stallings line is of unusual interest. Referring to the record it is to be noted that the ground current gradually reduced to a negligible value, which is probably accounted for in the reduction of the bus voltage as the system approached instability. Twenty-one cycles later the number 2 Stallings circuit cleared at Venice, allowing ground current to build up again on the number 1 circuit, this rise in current being proportional to the rise of voltage at Venice during the first voltage oscillation, occurring as the system became unstable. The faulted circuit was not cleared until after a total time delay of 54 cycles. At the instant the fault cleared, the number 1 phase 66-kv bus voltage at Venice had been reduced to 15 per cent of its normal value and the number 3 phase voltage to 25 per cent of normal. After the opening of the feeder breaker the voltage on the Venice bus partially recovered, but by that time the system was sufficiently far out of synchronism that instability set in, which is clearly shown on the record in the oscillatory character of the bus voltage. Since that time, high-speed ground relays and impedance relays have been installed and oil switches modernized on these and the remaining 66-kv radial feeders supplied by the Cahokia and Venice station.

During the last 5 years 6 instances of instability have been recorded on the system, one in each year except 1935 in which 2 cases occurred. An analysis of the underlying causes leads to some interesting observations. In 4 out of the 6 cases, loading of the Osage hydroelectric plant was very heavy, in fact near capacity. The lines from Osage thus were operating close to their static stability limits, a condition from which it might be inferred that these lines would be quite susceptible to instability even for light disturbances. This was the case, for in 3 of the 4 cases wherein Osage plant loading was heavy, instability was caused by disturbances originating on the low-voltage transmission system. The fourth case was caused by "dancing" conductors on 2 66-kv circuits out of the Cahokia substation. The resulting phase-to-phase short-circuits were cleared by the long-time-delay back-up overcurrent relays. The remaining 2 cases of instability already have been described.

From the viewpoint of the protection engineer, the most logical means of combating instability is through the medium of high-speed relays and switches. As mentioned, 4 cases of instability experienced on this system could be attributed to excessive loading of transmission lines. If such loadings are made necessary by economic conditions that transcend in importance the cost of high-speed relay equipment that will prevent their repetition, obviously the relays should be installed. The repetition of system instability caused by the phenomena of "dancing" conductors has been eliminated by the installation of high-speed impedance relays, not only to the 2 circuits involved in this case, but to 4 other radial feeders supplied by the Venice station. These 6 circuits also have lately been equipped with high-speed ground relays, which will prevent a repetition

of the disturbances described in connection with the oscillograph record of figure 4.

Several 66-kv bus faults at the Venice station have resulted in severe disturbances to the system, in one case resulting in instability. The application of high-speed bus-differential protection will effectively prevent the recurrence of these disturbances. This equipment was designed to effect complete isolation from the system, in 12 cycles of either of the 66-kv busses upon the occurrence of a bus fault involving ground. Field tests made after the installation was completed verified this. Briefly, the installation was effected by connecting the primaries of small auxiliary current transformers into the neutral wires of the several feeder current transformers. The ratios of these were so selected that the ratio of primary current in the high-voltage circuit to the current in the secondary of the auxiliary transformer was the same for all feeders. The secondary circuits from all these auxiliary current transformers on any one bus section were paralleled into 3 groups, and each group connected to one of the 3 coils of 3-winding transformer differential relay. The contact circuits of this relay then were arranged to trip all oil switches on this bus section.

In addition to the installation of the protective system, which included a new high-speed oil switch for the bus tie position, new bushings were installed on several of the 66-kv oil switches to replace the old solid type. All bushings were checked with the aid of a power-factor tester, and those found defective were rebuilt or repaired. It is believed now that the probability of bus short-circuits is much reduced, and that even if they should happen the differential relay protection should function rapidly enough to prevent any serious disturbance to the system.

A similar arrangement of differential protection has lately been applied to the 66-kv bus at Cahokia, and has had occasion to function, as previously described in connection with figure 4. As mentioned, both these applications operate only on ground current, thus permitting very simple and inexpensive installations that will operate at the inception of the fault on more than 90 per cent of all bus faults, and on the remainder at the moment a ground is involved.

Discussions

Of AIEE Papers—as Recommended for Publication by Technical Committees

On this and the following 14 pages appear discussions submitted for publication and approved by the technical committees, on papers presented at the sessions on power transmission and distribution, illumination, education, and conductor vibration at the 1936 AIEE joint summer and Pacific Coast convention held at Pasadena, Calif., June 22–26. As it becomes available, other discussion of papers presented at this convention will be published in later issues of Electrical Engineering. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in Electrical Engineering, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions of papers scheduled for presentation at an AIEE meeting or convention will be closed 2 weeks after presentation. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, AIEE headquarters, 33 West 39th Street, New York, N. Y.

Flashovers on Transmission Lines

Discussion and author's closure of a paper by L. V. Bewley published in the April 1936 issue, pages 342–54, and presented for oral discussion at the power transmission and distribution session of the summer convention, Pasadena, Calif., June 24, 1936.

P. L. Bellaschi (Westinghouse Electric & Manufacturing Co., Sharon, Pa.): This paper illustrates the extent to which flashovers on transmission lines can be estimated by relatively simple processes of analysis. In this respect the paper is a further contribution to similar studies by Fortescue, Monteith, and associates, and also to the previous publications by the author himself.

The refinement introduced in considering the normal frequency effect is particularly useful in determining the phase or circuit that may be involved by lightning. Another point of interest in this paper is the use of the lightning current distribution curve. Other investigators have used the lightning voltage distribution curve, which has likewise been determined from field data and experience. The lightning-stroke characteristics and the line constants assumed and used by the author are not materially different from those found in similar analyses such as in reference 19. Considering that even the best approach to the problem of line flashovers is as yet one of estimating values, the estimates deduced by the author are of the same relative order of magnitude as given in previous similar studies (reference 20).

It is amply apparent that the validity of such convenient charts and tables as the author gives in figures 5, 7, and 8 depends vitally on the assumptions that have been made. For this reason further progress in the analysis of lightning performance of lines depends largely on a close correlation of such charts and tables with field experience. Equally, if not more effectively, it depends on a strengthening of the basis of the assumptions with more supporting physical facts.

In the first place, the physical characteristics of the lightning stroke and the mechanism of the discharge require study.

Whether to use 200 or 400 ohms for the surge impedance of the lightning stroke depends on the correlation of such physical observations and data as these: Experimentally, and also theoretically, it is now quite well established that the core of the lightning-current channel is about the size of the human thumb. It is also known experimentally, from Schonland's work, that the propagation of the current from earth into the leader-stroke channel is at about a third of the speed of light. These are very helpful physical facts that should assist our judgment in setting up correct assumptions for line analysis and design.

Secondly, the importance of the lightning-current or lightning-voltage distribution curves cannot be overemphasized. For the purpose of developing a method of analysis, as Bewley has done, the curve of figure 1, which he has used, serves the purpose. But the results thus obtained are of relative value to the extent that this curve approaches or departs from the true "characteristic" of lightning discharges. As suggested in a paper by the writer (ELECTRICAL ENGINEERING, volume 54, August 1935, pages 837–43) and in the closing discussion, the current distribution curve must incorporate extensive field data if it is to represent the true "characteristic."

Still further, the voltage rate of rise at the point of incidence of the stroke to the line is another important factor that calls for careful consideration. It is quite possible that the voltage rate of rise varies over a greater range than is now suspected and that the lightning-stroke voltage may rise to crest in a time duration greater than one microsecond. In fact, the apparently good performance of lines having relatively close distances between ground and line wires indicates that the stroke at the point of incidence is usually not so steep as we now assume in our calculations of transmission line flashovers. Possibly a distribution curve for the voltage rate of rise is another of the important lightning characteristics that should be established for application not only in line analysis but also for other engineering purposes.

Field experience, when properly correlated, will also serve as a helpful guide in analytical studies of line performance. In addition, the means now available for producing direct strokes of lightning in the laboratory also contribute in solving practical and theoretical problems. In this connection, the lightning-stroke generator that has recently been developed at the Sharon laboratory provides a helpful means to investigate directly in the laboratory the lightning-stroke phenomena (*Electric Journal*, volume 33, June 1936, pages 273–75).

Further progress in predetermining transmission line performance then lies to a considerable extent in a more complete understanding of the physical factors underlying the lightning-stroke discharge.

C. A. Powel (Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.): This paper is a valuable contribution in that it brings up to date the material available on lightning severity. It is interesting to note that this paper based on lightning current data leads to the same general conclusions as previous work done some 3 or 4 years ago (references 19 and 20), but I cannot help wondering why the author plots the probability of outage of a line against lightning current. Flashover is caused by potential and the industry is used to considering flashover in terms of voltage. It appears to me that the preferable form of such a performance curve is that adopted by Fortescue and Monteith in which the level of protection desired is expressed as: "A permissible stroke in kilovolts plotted against the number of standard insulators necessary to obtain that level." In either case surge impedance must be assumed.

J. T. Lusignan, Jr. (Ohio Brass Co., Mansfield): The author again has given us an excellent treatise on the subject of lightning protection. As usual his text is clearly written and well composed, a point which I would like to emphasize in view of the difficulty encountered in following the "highly technical" articles offered by many engineering writers.

In arriving at some of his values, he has had to make assumptions because of the lack of complete knowledge at present of the factors involved. These he notes with reasons for the values he finally chose. In regard to his treatment of wood as an insulating member, I am afraid that he has not given it credit for as much impulse electrical strength as our laboratory tests have found it to have. On the fourth page of his paper he has given his principal thoughts on this.

In the footnote of this page he states. "Wood may add very little to the over-all strength until it equals in strength the flashover voltage of the insulator string itself." I am uncertain as to his meaning here. He continues, "It does not appear permissible to add the flashover voltage of the wood directly to that of the insulators." This condition we have found consistently in our laboratory tests, and have felt it to be due to the unequal capacities of the porcelain and wood insulations in series. The latter condition causes the voltage to be divided across the individual members in inverse ratio to their capacities, so that those of low capacitance, such as the porcelain insulators, will experience a higher initial voltage and flash over first, followed by breakdown of the remaining series wood members. If the latter are made long enough, of sufficiently small cross section, or treated to give a low internal dielectric constant, all of which reduces the internal capacitance of the wood relative to the insulator capacitance, then the wood will share more nearly equally the total imposed voltage and give the structure a higher breakdown strength.

The structures that the author has chosen as examples for demonstrating the use of his cleverly arranged curves do not show wood insulation to have any particular merit in handling direct strokes. I am sorry that he did not include the case of a wood structure supplied with a properly installed ground wire, such as a number of utility engineers have chosen for some of their high-voltage lines. In these cases the downleads at each structure have been carried clear of the top sections so as to preserve the insulation to ground there and have been terminated at ground points of comparatively low resistance. This has resulted in arrangements having very high insulation strength against lightning at comparatively low cost. At the same time flashovers to ground, rather than phase-to-phase flashovers only, are assured, thereby taking care of the relaying problem that Bewley notes.

L. V. Bewley: C. A. Powel asks why the lightning-expectancy curves were plotted as currents instead of voltage. It was primarily because the direct measurements have been current measurements (by magnetic links), and engineers have become accustomed to estimate lightning in terms of amperes. While it is true that the surge impedance enters either way, yet if the future discloses that our present ideas of surge impedance are wrong, it alone will need to be changed. The currents will remain fixed, since they were directly measured, but a derived voltage would suffer change.

P. L. Bellaschi points out, in effect, that the results given in the papers are no better than the field data on lightning, on which they are based, which of course is true.

We have a considerable number of current measurements, any one of which may be in error by 25 per cent or even more. We have nothing very definite on wave fronts, and, as Bellaschi remarks, it is beginning to appear that actual lightning fronts are longer than the one microsecond which has usually been assumed. The surge impedance is by no means settled. If we knew definitely the size of the core of the stroke and the velocity of propagation, we could more precisely calculate the surge impedance. Assuming the stroke to be a vertical cylinder of radius r and the part of the cloud contributing to the discharge to be of radius R; taking the return path to be uniformly distributed between r and R, the inductance is

$$L = \frac{2}{10^9}\left(\log\frac{R}{r} - \frac{1}{2}\right)$$

and if the velocity of propagation is v centimeters per second then the surge impedance of the stroke is

$$Z = vL = \frac{2v}{10^9}\left(\log\frac{R}{r} - \frac{1}{2}\right)$$

Using Schonland's value of $v = 1 \times 10^{10}$ and Bellaschi's value of $r = 1$, we find for various values of R:

R, feet	100	500	1000
Z, ohms	150	182	196

Had the velocity of propagation been that of light, these values would have been 3 times as large. We are assuming the retardation of velocity to be entirely the result of the relative inductance and capacitance. The corona envelope, determining the capacitance, would then be wholly responsible for the retardation of velocity. If, however, the retardation is partly the result of some sort of progressive breakdown phenomenon, then the surge impedances would be higher than those just given. It would appear, therefore, that the true value lies between 200 and 600 ohms. If we adopt the attitude that lightning calculations are comparative, rather than

absolute, it does not matter greatly what value we use for Z, so long as it is of the right order.

J. T. Lusignan pleads for more credit to wood, and he may be right. Such data as are available to me are far from conclusive. The tests to which I referred, made on a series combination of wood and insulators, showed an over-all flashover value not much different than the insulators alone, up to the point where the individual flashover of the wood was equal to that of the insulators. Thereafter the over-all flashover value increased as the length of wood was increased. A rule regarding the use of wood, which seems to be much favored, is to take the flashover value as equal to 100 kv per foot or as equivalent to an insulator unit; and add directly to the flashover value of the insulator string. On this basis, the case of a wood pole line, with proper ground wire, and down-leads to insure line-to-ground rather than phase-to-phase flashovers, appears very favorable indeed. Interesting alternatives are:

1. In the case of triangular configuration of conductors, an expulsion gap may be placed on the top conductor only. After it operates, the top conductor in a manner becomes a ground wire with respect to the other 2 conductors. Low footing resistances are imperative.

2. If the system neutrals are not required to be grounded through low impedances, a Petersen coil may be used with low-resistance tower footings. Then the stricken conductor acts in a manner as a ground wire with respect to the others, and its flashover is extinguished by the Petersen coil.

Impedance Measurements on Underground Cables

Discussion and authors' closure of a paper by R. L. Webb and O. W. Manz, Jr., published in the April 1936 issue, pages 359–65, and presented for oral discussion at the power transmission and distribution session of the summer convention, Pasadena, Calif., June 24, 1936.

W. F. Davidson (Brooklyn Edison Company, Inc., Brooklyn, N. Y.): In their very proper effort to confine their paper to discussion of the measurements on underground cables, the authors have passed by very lightly a matter which seems to me to justify further attention. It is the use of the a-c potentiometer for making measurements in connection with tests of the type here considered. In comparison with the more usual methods employing ammeters, voltmeters, wattmeters, and phase angle indicators, the potentiometer offers advantages of direct reading and a nearly uniform accuracy throughout its range, both with respect to magnitude and phase difference. Further, the data are in a form where they may be used directly without the need for extended computations.

It would seem that the a-c potentiometer has now reached a stage in the development where it should be used much more extensively in engineering measurements of many types. At the present time the high cost of the instruments appears to have been one obstacle toward their general use but more general demand in turn should lead to lower cost.

C. L. Gilkeson (Edison Electric Institute, New York, N. Y.): Because of other parallel conductors, such as pipes and cable sheaths, whose presence or location may be unknown, the authors have brought out very clearly that the calculation of zero-sequence impedance can be expected to be only a rough approximation to the actual value. It is also shown that, for test currents of less than 600 amperes, the measured zero-sequence impedance of cables, with binding tapes of magnetic material, will depend upon the value of residual current used in the tests. It is not always practical to use currents of the order of 600 amperes in measurements on installed cable. A method whereby the zero-sequence impedance of underground cables may be calculated by the use of certain experimental quantities, which may be obtained from field tests at moderate currents and laboratory measurements on cable samples, is developed in the recent report of the joint subcommittee on development and research

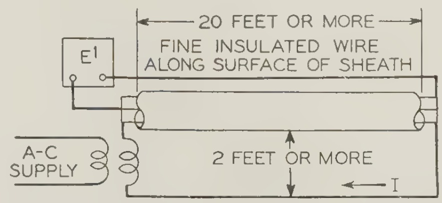


Fig. 1. Circuit arrangements for the experimental determination of quantities required for the calculation of the zero-sequence impedance of cables with steel binding tape

Set up to measure $Z_{11}' + 2Z_{12}' = 3E'/I$

Note: Instrument to measure E' should have a high input impedance and a sensitivity of 0.1 volt. Angle of E' with respect to exciting current is also required. An a-c potentiometer may be used or a vacuum tube voltmeter, determining angle by the "3 voltmeter method"

referred to in the paper (Engineering Report number 37). A brief outline of the method is given in this discussion.

In figure 7, the authors give a curve of the external component of the zero-sequence impedance of several sections of cable as a function of the distance from the Hudson Avenue station. The values of figure 7 are $^1/_3$ the difference between the measured zero-sequence impedance of the cables in place and the internal impedance of the cable. They include the resistance of the cable sheath, as well as the earth and metallic circuits parallel to the cable. A more general attack on the problem would separate the resistance of the sheath of the cable, under test, from the unknown quantities. The steps in such a solution would be:

1. The measurement of the zero-sequence impedance of cables or sections of cables in place. The test current may be of any convenient value, provided it is large enough to override extraneous effects.

2. If the cable has binding tapes of magnetic material, the internal impedance of a short section of each type of cable, as a function of current, should be determined from laboratory tests. The experimental setup is indicated in figure 1 of this discussion. For cables without steel binding tapes this quantity may be calculated from the dimensions of the cable.

3. From the measurements indicated in 1 and 2 an empirical term may be derived that is the equivalent impedance of the return path external to the sheath of the measured cable. This term is independent of the current strength and the constants of the cable, but may be a function of the location o[f] the cable section.

4. Through the use of this empirical term, an[d] curves of internal impedance, the zero-sequence im[-] pedance of cables of various sizes and at differen[t] values of residual current may be calculated. Th[e] impedances derived in this manner are directly ap[-] plicable only to cables in the same duct run as th[e] cable under test. However, if it is not feasible t[o] determine experimentally the equivalent externa[l] impedance of the return path for each duct ru[n] the test values from one location may be applied t[o] other situations of generally similar nature, wit[h] results which will be more satisfactory than thos[e] based on calculations alone.

The following paragraphs explain th[e] determination of the empirical term repre[-] senting the equivalent external impedance o[f] the return circuit and attempt to give [a] physical significance to it.

The zero-sequence impedance of [a] shielded cable with steel binding tape ma[y] be expressed as

$$Z_0 = (Z'_{11} + 2Z'_{12}) + 3\,\frac{R_{dc}Z_{ex}}{R_{dc} + Z_{ex}} \qquad (1$$

where $(Z'_{11} + 2Z'_{12})$ is the internal self impedance of the cable and is experimen[-] tally determined for a range of currents a[s] indicated in figure 1. It includes the re[-] sistance of the conductors and the reactanc[e] due to the flux within the outer periphery o[f] the cable sheath. When the cable does no[t] have steel binding tapes this quantity ma[y] be calculated. The quantity R_{dc} is th[e] resistance of the cable sheath, and $Z_{ex} = r_e + jX_e$ is the equivalent impedance of th[e] return path external to the cable sheath. This is the empirical term required.

The difference between the internal com[-] ponent of zero-sequence impedance and th[e] measured value, divided by 3, is the valu[e]

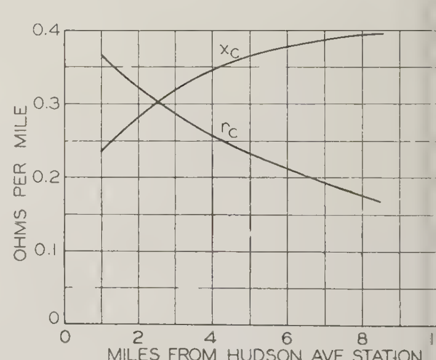


Fig. 2. External components of zero-se[-] quence impedance, Brooklyn cable tes[t]

X_c for ρ = 100 is 1.22 ohms per mile, no other metalli[c] structures

R_c for ρ = 100 is 0.09 ohms per mile, no other metalli[c] structures

which the authors have called the externa[l] component of the zero-sequence impedanc[e] $Z_e = R_e + jX_e$. The value of the interna[l] impedance must of course correspond to th[e] residual current at which the zero-sequenc[e] impedance was measured.

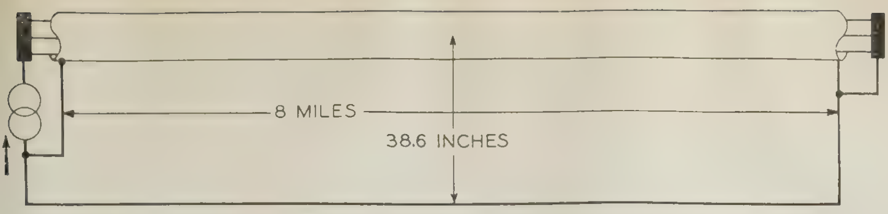
Then from equation 1

$$Z_0 = (Z'_{11} + 2Z'_{12}) + 3Z_e$$

and

$$Z_e = \frac{R_{dc}\,Z_{ex}}{R_{dc} - Z_{ex}} \qquad (2$$

Let r_c be the resistive component due to th[e]



ig. 3. Circuit representing average impedance of underground section 8 miles long, starting at Hudson Avenue station

Conductor resistance approximately that of a 350,000 circular mil copper conductor $Z_0 = 3E/I$

lux outside the sheath, x_e the reactance vith ground return corresponding to linkges due to flux external to the sheath, and R_{dc} the resistance of the cable sheath. Then:

$$Z_e = \frac{R_{dc}(r_c + jX_c)}{R_{dc} + r_c + jx_c} \tag{3}$$

Let

$$Z_e = R_e + jX_e = R_{dc}\,(a + jb) \tag{4}$$

Substituting equation 4 in equation 3 and olving for r_c and x_c, it will be found that

$$r_c = \frac{R_{dc}(a - a^2 - b^2)}{(a-1)^2 + b^2} \tag{5}$$

$$x_c = \frac{R_{dc}\, b}{(a-1)^2 + b^2} \tag{6}$$

Computed values of R_{dc} and values of Z_e, corresponding to various distances from Hudson Avenue station, have been substituted in equation 4 to determine values of a and b. Using these in equations 5 and 6, he values of r_c and x_c were determined, and he curves shown in figure 2 of this discusion were obtained.

It may be noted from the curves in the igure that, with increasing distance from he station, the resistive component dereases and the reactive component inreases. This is a condition which is to be xpected since near the station there would be a large number of cables, and in the congested part of the city near the station there would be many more buried metallic structures than there would be 8 or 10 miles rom the station. Calculations indicate hat when metallic structures parallel a ground-return circuit, current is drawn into hese structures, thus reducing the size of he inductive loop and reducing the reactive component, but at the same time increasing he resistance of the circuit.

In order to get some physical interpretaion of the curves of figure 2, the equivalent circuit is given in figure 3 of this discussion. This is a metallic circuit with the impedance of the ground-return part of the circuit epresented by a conductor in parallel with he sheath. It may be noted that the form of equation 3 is that of the impedance of 2 branches in parallel, which have impedances of R_{dc} and $r_c - jx_c$. Hence, an equivalent circuit to represent the zero-sequence impedance of a cable would consist of the nternal component $Z'_{11} + 2Z'_{12}$ in series with 2 parallel branches. One of these is he resistance of the sheath and the other is he impedance of a circuit, which for a particular section may be represented as a conductor of resistance r_c located at a separation from the cable such that its reactance with sheath return is x_c. The equivalent circuit in figure 3 is of this type. For a section of cable extending to a point 8 miles from Hudson Avenue station, the external conductor with a resistance r_c is approximately equivalent to a 350,000-circular-mil copper conductor and x_c corresponds to a separation of this conductor of 38.6 inches from the cable. A cable section extending one mile from Hudson Avenue would have in its equivalent circuit a 3/0 conductor at a separation of 10.8 inches.

R. L. Webb and O. W. Manz, Jr.: W. F. Davidson is quite right about the a-c potentiometer. It proved to be a very convenient instrument for taking the various measurements on these tests since, with it, the resistance, reactance, and phase angle quantities could be read directly. Ammeters, voltmeters, and wattmeters were used also, for comparison, but after a few check calculations of the impedance components the readings of these instruments were not used as it was evident that the a-c potentiometer could be relied upon with great confidence.

A brief description of the a-c potentiometer may be found in the National Electric Light Association (now Edison Electric Institute) *Bulletin*, April 1930, page 237. Very few of the instruments are available in the United States. The one used in these tests was borrowed from the Edison Electric Institute in New York.

C. L. Gilkeson's reference to the work of the joint subcommittee on development and research sponsored by the Edison Electric Institute and the Bell Telephone System is timely and appreciated. Their results should be of great assistance to the industry in determining, by calculation, the zero-sequence impedances of both cable and overhead circuits in transmission and distribution systems. Their report number 2*J*-8 entitled "Computation of Zero-Sequence Impedances of Power Lines and Cables" is available at the EEI general office as Engineering Report number 37.

The difficulty usually encountered in calculating the zero-sequence impedance for any circuit is arriving at a reasonably accurate assumption of the nature of and the equivalent location of the return current path with respect to the faulted cable or circuit. The results of several calculations using the methods proposed by the joint subcommittee are given in table I of the paper. Without the confirming test data it would be a question indeed as to which of 5 calculations were most nearly right, but with the guide obtained by tests on a few representative circuits, calculations for others may be made with a high degree of accuracy.

The writers are indebted to Gilkeson and to his office for their helpful suggestions and for the use of their a-c potentiometer in taking the impedance measurements.

It was originally hoped that the data presented in figure 7 of the paper might be used in determining the total zero-sequence impedance of any 3-conductor cable circuit in Brooklyn by simply adding them to the measured "internal" impedance of the cable in question. An attempt was made to determine the feasibility of such a procedure by additional tests which were made subsequent to those described in the paper.

The positive- and zero-sequence impedances of a 9,500-foot 3-conductor cable, operated at 4.5 kv, were measured. This cable contained no magnetic material. It is described as:

3-conductor, belted, paper insulation with lead sheath
350,000-circular-mil sector-shaped conductors
Approximate insulation thickness 125 × 80 mils
Approximate lead thickness 125 mils
Approximate over-all diameter 2,250 mils

The measured positive sequence impedance was found to be $0.0326 + j\,0.0286$ ohm per phase per kilofoot at 25 degrees centigrade.

The measured zero-sequence impedance was determined as $0.141 + j\,0.174$ ohm per phase per kilofoot.

Accurate "internal" impedance data were not available for this particular cable type but the resistance component could be taken from the positive-sequence resistance measurement, and it was used together with the "external" resistance which was obtained from an average of the 27-kv cable tests in the same general locality to arrive at the final value of zero-sequence resistance.

The "internal" reactance component was assumed to be the same as for the 27-kv circuits at high current values, making the zero-sequence reactance assumed to be equal to the average value obtained on the 27-kv cables in that area. The figure for zero-sequence impedance obtained in this way was $0.144 + j\,0.137$ ohm per phase per kilofoot.

The resistance component did check fairly well with the measured value but the reactance value was 21 per cent low.

The smaller size of the cable is possibly a cause of some of the error in the reactance component but it is more probable that the different nature of the return current path and the resulting difference in the "external" impedance of the 4-kv cable was the major reason for the 21 per cent error.

In routing the various feeder types through duct banks and manholes, it is the practice, in Brooklyn, to space the 4-kv distribution feeders at a considerable distance from the 27-kv cables. The lead sheaths of the higher voltage and larger cables, which doubtless form an important part of the grounded return path for either size of cable circuit, were located much farther away from the 4-kv circuit than from their own conductors, operated at 27 kv. This circumstance alone may account for nearly all of the 21 per cent error in the calculated zero-sequence reactance.

It is interesting to note that, even for this cable, with a different location of resultant return path, the resistance component of zero-sequence reactance did not change appreciably from the value obtained for the 27-kv cables of the same conductor cross section. This tendency for the zero-sequence resistance to remain nearly constant

per unit circuit length for all cables of the same conductor size was noticeable in all of the tests. Any variation in total impedance was occasioned by a change in the reactance component, apparently because of differences in the cross section and the location of the resultant grounded metallic return path of the system.

Tests on Oil Impregnated Paper

Discussion and author's closure of a paper by H. H. Race published in the June 1936 issue, pages 590–9, and presented for oral discussion at the power transmission and distribution session of the summer convention, Pasadena, Calif., June 24, 1936.

J. B. Whitehead (The Johns Hopkins University, Baltimore, Md.): The scope of the author's experimental research attacking the problem of the life of impregnated paper as described in the summary is very comprehensive and inspires the reader with the hope that here at last we are to find answers to many questions which so far have baffled many research workers and are still unsolved. Unfortunately the high hopes excited by the summary are not yet realized. Although the author is reporting the results on one of 3 main divisions of his program, it must be admitted with regret that after so careful a study, there is as yet a notable absence of uniformity of result and of quantitative relationships sufficiently repeated to warrant general conclusions.

Little exception can be taken to the author's survey of the number of hypotheses that have been advanced as to the various contributory causes which may enter into the deterioration with time of impregnated paper. One upon which there may be some question is 1*c* in connection with which it is suggested that the addition of oxygen or hydrophilic materials, in aiding the adherence of compound to paper, may lessen the tendency to cause gas spaces and so may increase life. It might have this effect in the capillary fibers, but if there is present a tendency to gas formation, it is quite probable that such formation will actually take place, even though it might be in some other location. Moreover, it remains to be shown that a possible advantage on this account would be greater than the serious disadvantage of increased dielectric loss which usually accompanies the addition of oxygen.

The test cells, the test specimens, and the provisions made for varying pressure and temperature conditions and also for the subsequent close study of chemical and physical changes following the tests are all admirable. All research workers in this field will envy the facilities and personnel at the author's disposal. If these intricate questions are susceptible of clear-cut answers, it would certainly appear that they should be forthcoming from such a careful combination of well-considered attack, unstinted resources, and experienced talent.

The results reported have to do principally with the question of power factor changes in life as related to the presence of the gases oxygen, nitrogen, and carbon dioxide. It is difficult to follow the author in his conclusion 2 that the specimens having longest life owe their life to the introduction of limited amounts of oxygen. Specimens free of oxygen and containing carbon dioxide are found in the same group and other specimens containing oxygen are found well down in the short-lived class. It is also difficult to see how, as based on the data presented, general conclusion 6, claiming that methods had been developed for selecting materials for impregnated paper, can be drawn.

Of special interest is the conclusion that increase in conductivity of the oil leads to shorter life. This is in general accordance with the observations of other workers. Also of interest is the superiority shown by the oil of naphthenic base. Both these results are in accord with an extended series of accelerated life tests reported by the writer and co-workers under the title "The Life of Impregnated Paper" at the Chicago Summer Convention, 1933. The principal results, however, of this paper indicated that, as based on accelerated life tests of more than 100 carefully constructed samples, uniform in all respects except as to the oil, which was varied over a wide range, the capillary and impregnating properties of the oil-paper combination have a much greater influence on life than the basic properties of the oil.

Doctor Race's paper, in my opinion, must raise with us a serious question, namely, is there really a probability that the causes of the deterioration of impregnated paper are to be found in the underlying chemical properties and minute physical differences in the oils which he and others have been studying with so much care? If so careful a program can lead only to general indications as related to equally uncertain hypotheses, is there not something wrong somewhere? The best knowledge that we have of the nature of the actual electric failure of oil is that it is due to ionization by collision. Now this process begins with the presence of free ions and their subsequent tendency to increase. In my opinion the most powerful original cause of oil deterioration is its free ion content as measured by the product of its conductivity and its viscosity. The destructive influence of ions is to be found not so much in their effect on power factor and loss, but in the continuing hammering action that they have upon the structure of the oil as the result of alternating cycles over prolonged periods of time. If a series of studies be made with the author's equipment under conditions that eliminate, as nearly as possible, all other factors except the ionic content and those influences which tend to increase it, my belief is that a very much more definite series of results and conclusions will follow.

L. J. Berberich (Socony-Vacuum Oil Company, Inc., Paulsboro, N. J.): The author has made a significant contribution to the field of electrical insulation in designing the equipment for testing oil impregnated paper, described in his paper. His specimens come closer to simulating the closed system involved in the several types of cable than any heretofore proposed. The simple laboratory tests usually made on the constituents of cable insulation serve as a basic test for establishing the general suitability of the materials but give little information as to the subsequent behavior in a cable under operating conditions. Up to now the only test in which reliance could be placed is the expensive so-called "load cycle" test on factory-produced cable. If the author's test can replace this cumbersome test on factory-produced cable a very urgent need is satisfied.

In such a test that there still remains, however, some danger of being misled because the test is necessarily accelerated in order to conserve time, and because the specimens must necessarily be small in order to make possible their assembly and testing in the laboratory. Also, the micromethods of analyses required may amplify factors of uncertainty. The chemical changes produced in the oil or paper are usually small, which makes it doubly difficult to evaluate them by the micromethods. The few results of microanalyses which are given in table V of the paper appear to bear this out, for no definite conclusions can be drawn from them. Thus, it appears that the test must be carried out with extreme care and caution if it is to be of value. Moreover, such things as small variations in the tension of the paper tape while applying it to the specimen can influence the life of the specimen markedly. This indicates that it is dangerous to base conclusions on the results of a single specimen. For these reasons, specimens should be tested in duplicate or perhaps even in triplicate. The paper gives no information as to how close an agreement can be obtained among several specimens. It is hoped that the author has eliminated many of these factors of uncertainty. The 3 types of specimens he describes should enable him to simulate almost any condition which obtains in the several types of cables.

The lack of a reliable and inexpensive test for evaluating the constituents of cable insulation has materially retarded the improvement of oil-impregnated insulation. In the last few years the refining of oil has been revolutionized through the use of selective solvents. More has been learned of inhibitor action in oils. Undoubtedly some changes have also been made in the manufacture of cable paper. A reliable test would facilitate greatly the finding of the optimum combination of these 2 materials for cables and capacitors. Since the present load-cycle test on factory cable is quite expensive, there has been a reluctance to change from the existing state, and quite reasonably so. Perhaps the author's test, if it becomes generally recognized, may open up a new era of development of insulation for high-voltage cable.

Herman Halperin (Commonwealth Edison Co., Chicago, Ill.): The author has given an interesting and valuable progress report on tests of miniature cable samples. Further similar data from him and others will be welcomed.

I am not sure whether it was intended that the results of the tests were meant to apply directly to cable having insulation known as the solid or ordinary type. The test cells had a free supply of oil for the insulation at all times, indicating that the tests do not directly apply to the ordinary type of cable.

Cables of the ordinary type may have 5 or 10 times as much insulation as the samples

tested, and would have pressure and vacuum phenomena and migration of compound that were not particularly simulated in the test samples. Even so far as applying to oil-filled cables there are some doubts, because experience and theoretical considerations have indicated that when there is a large supply of oil surrounding the sample under test, heat may be dissipated much more readily than is the case for a lead-covered cable; this means that development of particularly localized deterioration leading to failures is inhibited because unnatural conditions are produced for heat dissipation.

It is fully appreciated that as a matter of economy, excellent results may be obtained by tests such as those conducted by the author, and the indicated conclusions may be later checked by accelerated aging tests on full-sized lead-covered cable samples in air.

In connection with the statement that failures occur due to ionization, it is to be noted that samples 156 and 157 had, according to table IV, negative ionization factors throughout the tests. Does the author have any explanation of the meaning of these negative power factor-voltage curves?

Data obtained on experimental and on commercial oil-filled high-voltage cable in Chicago indicate that negative ionization factors are associated with chemical deterioration of the oil rather than gaseous ionization. In our tests on deteriorated cable, small negative values were obtained at room temperature and higher values at elevated temperatures, the most deteriorated cables having the highest negative ionization factors.

Samples 172 and 173, which were identical with samples 156 and 157, respectively, except that thinner paper was used, showed positive ionization factors. Perhaps the results indicate, also, that the nature of the paper may be a contributing factor in the deterioration process.

It is to be noted that in sample 160, charring occurred in only the middle layers of insulation. According to D. M. Robinson's theory on the mechanism of failure, carbonization in single-conductor cables must be connected to the conductor or sheath, the termination of the path sometimes being microscopic in size. Does the author have any data on this point?

The data presented do not seem to show any consistent relation between the power factor and the life of the samples. Oxidation may increase the losses, but does not generally seem to decrease the life.

Regarding the author's conclusion that the presence of polar materials aids the wetting properties of impregnating oils, does this mean that the addition of rosin to mineral oils would improve the characteristics of the solid type of cables?

Further comments on the summary of theories and hypotheses at the beginning of the paper are as follows:

1*b*. By "nominally gas-free liquid-filled system" I assume that some dissolved gas is considered which causes the increase in dielectric strength with pressure.

2. It is my understanding that gas evolution is mainly produced by bombardment and not by heat, although heating in localized regions accompanies bombardment.

2*a*. The statement on increase of dielectric strength with temperature probably is meant to apply to gas-free oil-filled insulation. Insulation of the ordinary type contains some free gas, and the dielectric strength increases with temperature up to, perhaps, 60 or 80 degrees centigrade for cables having low power factors. Probably this is due to an increase in pressure as a result of the heating.

W. F. Davidson and **R. N. Evans** (Brooklyn Edison Company, Inc., Brooklyn, N. Y.): The methods for studying oil impregnated paper outlined in this report afford many attractive features. The ability to control conditions would seem to be much greater than when tests are made on cable samples or full-size capacitors, and correspondingly, it would be possible to investigate an increased number of variables or to make duplicate tests. It seems a little unfortunate that the author has chosen to follow the former alternative entirely because the present paper lacks any data to show the reproducibility of the results. In spite of the careful control that apparently has been obtained, one must question the validity of drawing any conclusions even of the general form suggested by numbers 2 and 3 of the summary.

The use of micromethods for the examination of the samples is certainly to be commended as an important step in the interpretation and diagnosis of changes occurring during the life of oil insulation. Possibly with some modification they can be extended to good advantage to the examination of sections of cable removed from service or tests in the laboratory according to some more or less standardized load-testing procedure.

However, further development of the methods is necessary before they can satisfactorily meet all of the requirements. Although micromethods offer distinct advantages in permitting the use of samples of very small weight, they generally necessitate a sacrifice in accuracy and precision of the test methods. The application of chemical micromethods to the heterogeneous mixture of the paper and oil is beset with a major difficulty, namely, the nonuniformity of the sample. Complete and rapid separation of the oil from the paper presupposes a knowledge of the absorptive capacity of the paper for chemical bodies which do not correspond to the original average composition of the oil. In some cases, as is pointed out by the author, the presence of minute paper fibers may introduce serious difficulties.

The neutralization number values reported in table V represent the acid content of that portion of the oil which had not been removed from the paper by the centrifuge. Where interrelation between chemical tests is sought, arbitrary procedures for extracting the sample for the several tests may be questioned. It may have been of interest to readers to point out that the volume of alkali required to neutralize the acid in a sample weighing 0.05 gram, assuming the largest tabulated neutralization number, is 0.003 milliliter—a volume which would require a special microburette for measurement. Unless a typographical error has been made, a burette of this type would merit description.

With regards to the molecular weight determinations, if the mean of the 1, 2, 3 portions is taken it is found that in 4 examples the greatest variation from the mean is 3 per cent or less, whereas in the remaining 2 examples it is 9 per cent and 13 per cent. It follows that for a sample weighing 0.2 milligram the stated sensitivity of the balance (+0.01 milligram) would account for the variations of 4 of the examples listed in table V and if the sample weighed 1 milligram the variation of the observed molecular weights would be only 3 times the sensitivity of the balance. When one considers the uncertainty caused by the presence of the paper fibers and the difficulty of obtaining a representative sample it must be agreed that 4 of the 6 examples exhibited differences in molecular weights which may well be traced to observational errors.

The soluble copper content of high-voltage cable oil samples from many cables has never been observed to be greater than 10 parts per million, except in one case of excessive deterioration with the formation of an unstable solution. Several synthetic copper soaps have a solubility in high-voltage cable oil of approximately the same magnitude. Since the stated limit of the spectrographic test is 100 parts per million it would appear that a more sensitive test is required in order to relate the behavior of the soluble copper to actual cable operation.

G. M. L. Sommerman (American Steel and Wire Co., Worcester, Mass.): The author and his associates are to be commended on their successful application of microanalysis to the testing of electrical insulation.

With regard to the test specimens, it appears from figure 1 that the layers of insulating paper were applied as a continuous sheet instead of as layers of tapes usually employed in paper cable construction. This probably alters the breakdown characteristics, as it has recently been shown very clearly by D. M. Robinson [IEE (Great Britain) *Journal*, volume 77, 1935, page 90] that the electrical breakdown of paper cables consists of the formation of a carbonized track which progresses radially through the gaps between successive turns of paper tapes and tangentially along the interlayer spaces.

Because the specimens are covered with oil while under test, the results are strictly applicable only to oil-filled cables and not to solid-type cables. In these experiments the principal effect of the temperature cycles seems to be a partial breathing in and out of the saturating oil. In solid-type cables, possible migration of the saturating oil and stretching of the lead sheath must also be taken into account

Concerning the benefits imparted by the addition of hydrophilic substances to cable saturants by improving the bond between saturant and paper, it is worth noting that some cable manufacturers have for a number of years been adding resinous substances, which are hydrophils, to their saturating compounds, partly for this purpose.

With regard to the effect of dielectric loss on the dielectric strength, it should be pointed out that dielectric loss has no effect unless it is sufficiently high to cause a thermal-type failure. For satisfactory service operation, it is required that only the cable power factor be kept below a value such that the dielectric loss under operating voltage is small compared with the maximum allowable operating copper loss. Since the dielectric loss increases as approximately the square of the applied volt-

age, life tests, if too greatly accelerated, cause specimens of medium power factor, but otherwise very stable, to fail thermally. In other words, greatly accelerated life tests often give results which are more a measure of the power factor-temperature characteristics of the insulation than of insulation life under service conditions. Such tests will not give a true indication of the optimum amount of conducting material to be added to the cable saturant.

Conclusion 5 points out that the gas evolution produced by the effects of electric stress is less for a naphthenic oil than for a paraffinic oil. This conclusion has also been reached as a result of tests on small samples made at our laboratory. In this case the oils were of the very viscous cylinder stock variety suitable for use in solid-type cables. One oil of an extreme paraffin type showed over 10 times the wax formation that a highly naphthenic oil showed, as the result of polymerization and condensation produced by electric stress tests.

H. H. Race: Since the work described in this paper was started we have had numerous requests for details of the methods which we have been developing during the last few years. Knowing that a number of laboratories were working on the general problem of the electrical, physical, and chemical properties of oil impregnated paper, it seemed worth while to present a paper whose major object was the description of these new test methods. It is hoped that future papers will show that the results have been worth the effort.

The list of hypotheses indicates that the number of variables which may affect the life of oil impregnated paper is large. In planning the work we were faced immediately with the choice between an intensive study of the effects of changes in a few variables, making specimens, say, in triplicate, or of an extensive study to learn the factors that would cause large differences in behavior. At the beginning, therefore, I chose the latter course so that with given facilities I could look for major differences with 3 times as many combinations of variables. Check tests are being made on the specimens which look most interesting.

In addition to the above general statements I should like to comment on the following specific points.

In commenting on conclusion 2, I think J. B. Whitehead has misinterpreted my statement which points out that all specimens made from standard 0.0065-inch cable paper having a life greater than 52 hours contained either small quantities of hydrophilic materials purposely added to the oil or a limited amount of oxygen, which, by combining with the oil, produces hydrophilic oxidation products. Specimens 172 and 173 are not directly comparable to the others listed in table II since they were built with 0.0005-inch kraft capacitor paper and therefore had 13 times as many layers to give the same total thickness as specimens made from 0.0065-inch kraft cable paper. I believe this explains their long life.

I believe Whitehead is right in stating that the electrical failure of oil is probably caused by ionization by collision. However, in most cases this probably occurs in a gas phase and therefore depends upon the liberation of gas in solution in the oil or upon the evaporation of the liquid itself at localized hot spots or low-pressure regions. Inge and Walther have discussed these mechanisms recently in *Technical Physics of the U.S.S.R.*, volume 1, 1935, page 539. For these reasons it seems to me that the degree of degasification and the tendency of an insulating liquid to decompose, liberating gas under high electric stress, may be as important as the free ion content of the liquid.

W. F. Davidson's comments regarding difficulties and disadvantages of micromethods are entirely justified by our experience. However, if such methods can be made practicable, the advantage of using small, carefully controlled specimens should justify the effort. I presented our methods and results to show frankly the variations present in these methods in their present degree of refinement. Such methods are developing rapidly and give considerable promise of aiding in studies such as these. In general, although they may be difficult to interpret, electrical methods are more sensitive than chemical methods for observing very small physical and chemical changes, which might not otherwise be detected. The need is to refine the chemical methods so as to be able to interpret in chemical terms these observed electrical changes. It is hoped that this paper will serve to stimulate the application of microtechnique in this important field.

A description of a burette to read 3 cubic millimeters was requested. The Scientific Glass Apparatus Company, Bloomfield, N. J., manufactures microburettes with which a sensitivity of 0.1 cubic millimeter is possible. Many other types of microburettes have been described in the literature, some claiming readings of cubic millimeters to the third decimal place.

Herman Halperin's statement that oil migration, and therefore pressure and vacuum phenomena, are entirely different in our thin-walled specimens than in commercial cable having many times the insulation thickness is correct. In the course of this investigation we are obtaining considerable data on the effects of oil viscosity and paper density, which I hope to present later.

Halperin also asks for an explanation of negative ionization factors. (The use of the term "negative ionization factor" appears to be an unfortunate misnomer since gaseous ionization must be absent and an entirely different mechanism hypothesized to explain the result.) The most logical explanation appears to me to be based upon space-charge polarization. Suppose the free ions present in the liquid migrate so as to build up space charges at the paper interfaces or at the electrodes and suppose the number of these ions per unit volume is limited. Then the higher the voltage gradient the more rapid the space charge formation, resulting in saturation during each half cycle so that the dielectric loss caused by free ionic motion does not increase in proportion to the square of the voltage gradient. This is indicated then by a decrease in the apparent power factor.

Halperin and G. M. L. Sommerman both raise the question as to whether the addition of rosin to solid type cable oils should be beneficial from the standpoint of wetting. I believe that the mixtures of rosin and oil to which they refer contain up to 15 per cent of rosin, which is a much larger proportion than is necessary to give wetting. In our experiments the order of magnitude of polar addition products was about 0.1 per cent (see table II). The addition of larger quantities of polar materials often results in appreciable increases in dielectric loss.

Porcelain for High Voltage Insulators

Discussion and author's closure of a paper by D. H. Rowland published in the June 1936 issue, pages 618–26, and presented for oral discussion at the power transmission and distribution session of the summer convention, Pasadena, Calif., June 24, 1936.

J. J. Torok (Corning Glass Works, Corning, N. Y.): This paper is indeed very interesting and timely as only a few insulator papers written during the past 10 years have tried to approach the problem of line insulation from a fundamental angle. The insulator designer deals principally with the mechanical and electrical properties of dielectrics. It is quite essential for him to know not only the statistical values of the mechanical and electrical properties but also why the limits of his materials are in a particular region. Furthermore, it is to his interest to extend these limits as much as possible. These are the fundamentals of engineering advancement and the author seems to have struck this keynote.

He proposed that tests be made on samples of material and from these tests predictions be made of the mechanical strength of a specific article of that material. The results of tests on unglazed porcelain and on one type of glass, shown in table I, indicate a rather favorable comparison for glass. However, he finds that the performance of unglazed porcelain is improved by applying to it a glaze that is under considerable compression. A proportional improvement in glass can also be obtained by several methods known to the glass art.

Some 60 years ago glass workers found that by placing the surface of glass under compression its strength was greatly improved. One way of accomplishing this, as described by Schott in 1892, was to "flash" the surface with a thin layer of glass having a lower expansion coefficient than the glass body. This method is identical with that which Rowland has described in the case of porcelain covered with the + glazes. This has the disadvantage, however, that there is a very definite upper limit to the amount of strengthening that can be accomplished in this manner on account of the high shear forces introduced at the interface between the surface layer and the body, which result in spalling or flaking off if the difference in expansion is too great. A better and more practical method, and one that is being commercially used in the glass industry at the present time, is that of so controlling the cooling of a glass article that a definite temperature gradient is introduced while the material is still plastic. Then, upon final cooling, the temperature gradient is replaced by a stress gradient with the external layers of the glass in compression, the highest compressive stress being in the

urface. By this method the strength of ıe glass article may be increased as much s 4 times and the percentage spread in a iven series of tests between the maximum nd minimum breaking stresses is much educed. Glass rods so treated will compare very favorably in their properties with orcelain having a special glaze, or glass oating.

As Rowland has pointed out, the condiion of the surface of a ceramic material lays a most important rôle in the ultimate ıechanical strength. This applies especially to glass, which appears to have alıost unbelievable strength when precauions are taken to eliminate the effect of urface flaws. For example, after specially reating the surface of some test glass rods /4 inch in diameter, which however were ot given special thermal treatment, they ere loaded to about 40,000 pounds per quare inch maximum tension in a bending est and supported this load for the duration f the test, a period of 11 months. A. A. riffith (Royal Society of London *Philoophical Transactions*, series *A*, volume 221, 920, pages 163–98) working with glass bers reports strengths of 498,000 pounds er square inch. It is such results as these hat raise serious doubt as to the validity of ıe application to this material of a statisical formula such as Rowland has made. nother reason for this contention is that ıe surface condition and treatment of the est sample were probably quite different rom those obtained in finished articles. lass as a material, if properly treated, ossesses great strength. To utilize this trength glass suspension insulators now on ıe market are especially treated in the egions where load is applied, resulting in a roduct with a uniform and unusually high trength.

In connection with Rowland's experiıents, it would be interesting to know if in is calculations of compression in the glaze e has been abie to account fully for the ıcrease in strength of his experimental amples.

. B. Whitehead (The Johns Hopkins Uniersity, Baltimore, Md.): Transmissionne voltages range to the highest values tilized in power service. Consequently ıe very best and permanent dielectric maerials are demanded for line insulation. he requirement of permanence under all eather variations has, in the course of experience, led to the selection of ceramic maerials in general, and of porcelain in parcular. Its dielectric strength is high, its ielectric loss almost nil, and consequently, onsidered from the standpoint of insulaon alone, porcelain may be said to meet all ıe requirements.

Nevertheless, in the design of porcelain ısulators, the inherent electrical properties re completely subordinated to those of ıechanical strength. If the mechanical esign is sufficiently liberal, the electrical esign, speaking generally, will take care of self. Sound mechanical design, however, a major problem, and has engaged the ery best thoughts and efforts of porcelain ngineers for many years. The reason is ıat the inherent mechanical properties of orcelain are just about the worst that ould possibly be had for the support of eavy overhead lines. The material is hard, brittle, and has little or no yield to the normal vibrations and motion of heavy overhead cables.

It is all the more remarkable, therefore, that such progress has been made, and that porcelain insulators are available for meeting with great reliability all the demands upon them. This paper is an outstanding example of the application of scientific analysis and experimental study to the causes of breakage of porcelain insulators, and of the development of effective corrective measures. The surface crack, as a forerunner of trouble, has long been recognized. The outstanding feature of the work in question, however, is in its showing in quantitative experimental studies, the importance of internal tension and compression in the surface layer, and in the control of these forces by control of the material and thickness of the glaze. The convincing figures of performance, utilizing the new principles uncovered, indicate a sound step of progress in line insulator design and performance.

W. A. Smith (Ohio Brass Co., Barberton): The author has called attention to 3 important factors that affect the performance of porcelain in service. These are glaze, variations inherent in the material, and effect of duration of load on mechanical strength. The author is to be commended for the frankness of his approach to the problems under discussion. However, I feel some of his statements are not of general application and might be modified.

Ceramic materials are, in general, not isotropic, that is, their properties are not alike in all directions or in all parts of a given piece. A principal cause is plastic flow in cooling, as a result of which the outer layer tends to be in compression and the inner in tension ("Electrical Properties of Glass," J. T. Littleton and G. W. Morey, John Wiley & Sons, Inc., New York, N. Y., 1933). Cast iron, which metal most closely resembles porcelain or glass, may possess, to a striking degree, the outer layer in compression and the inside in tension. Such a condition tends to reduce the total strength of a member when tested in tension but to increase it when tested in bending. The thicker the piece, the more pronounced is this condition likely to be. It is further accentuated by the use of a compression glaze. The fact that the mechanical strength of pieces made from ceramic materials can sometimes be increased by deliberately placing the outer layer in compression, as by appropriate chilling during the cooling period, has long been known. However, because the glass phase characteristic of all ceramic products has no definite yield point and tends to flow when subjected to moderate loads applied over long periods of time, there is reasonable doubt as to the permanence and life of products treated in this manner.

In any particular case, the effect of glaze on the strength of a piece of porcelain obviously depends upon the thickness of the porcelain. It also depends upon the nature of the body composition and its firing history, because tests on bodies of a composition and treatment differing from that used by the author do not show such a marked increase in strength. What is really under discussion is the well-known notch effect, and the large increase in strength obtained by glazing may be due in part to the use of a body in which, when unglazed, the notch effect is high.

Referring to figure 10, showing suspension insulators broken under impact load, it would have been more enlightening if the tests had been elaborated to the extent of determining for each unit the maximum resistance to impact. All we know at present is that, under a blow of unknown energy, one group of specimens broke, whereas the other did not. The undetermined difference in shock resisting ability might be large or small.

In calculating the modulus of rupture, the general practice is to apply to an isotropic porcelain the familiar bending-moment formula that is rigorously applicable only to uniform materials. Therefore, I would prefer to see "apparent modulus of rupture" substituted for "modulus of rupture."

Ceramic products are analogous to castings in many of their properties and show a corresponding range of variation in their mechanical ultimate strengths. For this reason, curves such as those shown in figure 11 constitute one of the most valuable means available for manufacturing control. In using such a curve, the author states, at the foot of page 623, "the testing of 10 insulators will give a figure very close to the true average." This statement is true for some characteristic curves but not at all for others. With material having a distribution such as that of the unglazed ware of figure 11, where the spread is great and a considerable percentage of the material lies in the extreme ranges, tests on so few as 10 pieces give undue weight to chance selection. This is clearly recognized in the American Society for Testing Materials Specification *D*-116–30, for determining an average value for the mechanical strength of porcelain by testing in tension a limited number of samples. This specification stipulates as follows: "Any results, whose deviation from the mean of the deviations is more than 3 times the mean of the deviations, shall be discarded." The purpose is to secure samples from the middle of the distribution curve, in the neighborhood of which the true average will lie.

Rowland's method of applying the distribution factor *F* to an average test value when properly determined is believed to be quite sound.

With some of his conclusions I am not in full agreement. In the following, the numerals refer to the correspondingly numbered paragraphs of his summary.

1. "The present general method used for arriving at guaranteed mechanical values for insulators using ceramic dielectrics is insufficient." To date, the practice has been to recommend a maximum design loading of from 35 to 40 per cent of the short-time ultimate. The method indicated in the numerical examples on page 625 offers a more rational approach provided:

a. Distribution and time loading factors have been established from tests on a sufficiently large number of pieces.

b. Loading tests on sample bars correlate satisfactorily with tests on assembled insulators. In our experience, such a correlation is in some cases close and in others not, as may perhaps be expected. Furthermore, it is not necessarily to be presumed that such a correspondence should always exist. Results on a group of test bars broken in bending may not necessarily correspond to those obtained in an insulator using porcelain of a much more complicated shape, wherein the material may be placed either in tension, shear, or compression. For ex-

ample, tests by Parmelee and Kraebenbuehl, author's reference number 7, show that, of 6 different samples of porcelains, those which tested high in tension did not necessarily test high in compression.

3. "All indications point to surface strength as being of fundamental importance to the proper performance of insulator dielectric." This is accepted as applying only to bodies of specific composition and firing history.

4. It is possible "to predict the probable variations in quick strength of any insulator design by a simple calculation based upon the modulus of rupture obtained from a number of laboratory samples." This statement is rather sweeping. In our experience, it is in some instances possible to so predict and in others not.

5. "Uniformity of test values is not, by itself, a criterion of good porcelain." If the tests are made continually and on a sufficient number of pieces to be representative of the product, uniformity of test values is believed to be one of the best criterions of good porcelain, provided that experience has proved the material to be "good" for its intended use in the first place.

9. "The testing of relatively few specimens is a source of error in arriving at the correct values to be used in the formula." Since only the true average can be approximated by testing a limited number of pieces, this average should be obtained as called for in ASTM Specification *D*-116-30.

10. "It is believed that, for the first time, the important factors which materially influence insulator life are evaluated." This statement is felt to be too broad for the material covered. Dense porcelain, or the absence of porosity, is taken for granted. In view of past bitter experience, the need for watchfulness in this regard should not be overlooked. Furthermore, inspection of many insulators that have cracked under conditions where glaze or loading were not factors or obvious importance, has convinced the writer that temperature stresses, superimposed upon those left in the porcelain after firing, plus those due to mechanical loading, are vitally important.

This paper is a welcome contribution to the literature and a better understanding of the factors, upon which it lays emphasis, will lead to a more intelligent use of porcelain and ceramic products in general.

D. H. Rowland: J. J. Torok mentions the fact that it has long been known that glass can be considerably strengthened as a result of placing its surface under compression by "flashing" the surface with a thin layer of glass having a lower coefficient of expansion than the interior glass body. He states that there is a definite upper limit to the effect that can be accomplished in this manner due to the shear forces which exist between the outer layer and the body which cause the glass to flake off. Probably the reason that no trouble of this kind has been experienced with porcelain is because porcelain, unlike glass, is composed of a number of small silicon dioxide particles cemented together by a matrix of melted feldspar. Thus the surface of the unglazed porcelain presents a number of microscopic particles to which the glaze can firmly anchor itself and thus establish an exceedingly strong bond which will easily resist any shear load that it has been possible to build up between the porcelain and glaze by adjusting their differential coefficients of expansion.

The second method of placing the surface of glass in compression, as mentioned by Torok, has indeed been known for a long time. An extreme example of this is the familiar Prince Rupert's drop which consists of a drop of glass which has been chilled quickly by dropping it into water. Such a drop is amazingly tough to mechanical shock but when a small piece of the tail is broken off the internal strains within the glass are unbalanced with the result that the glass explodes.

Any quick cooling method of obtaining initial surface compression requires that the body of the glass be under considerable strain so that if it is chipped the failure spreads through the entire piece. Such a condition is unsatisfactory for insulators.

With a 2-ply porcelain structure made up of glaze on the outside and porcelain on the inside it is possible by controlling the respective compositions of the glaze and porcelain to anneal perfectly the latter and to eliminate appreciable strains throughout the great mass of porcelain while at the same time placing the surface under initial compression.

In answer to Torok's question regarding the calculations of the compression in the glaze fully accounting for the increase in strength of the porcelain, we have not as yet been able to evaluate the factors involved sufficiently accurately to warrant a calculation. This is because there is a thin layer between the glaze and porcelain the characteristics of which are unknown, and this makes a calculation difficult.

W. A. Smith states in his third paragraph that: "What is really under discussion is the well-known notch effect, and the large increase in strength obtained by glazing may be due in part to the use of a body in which, when unglazed, the notch effect is high." A study of table I indicates that glazing, in itself, may weaken unglazed porcelain as much as 50 per cent so that it is evident that, contrary to Smith, the "notch effect" is not the governing factor for if this were true any type of glaze which smoothed the surface would increase the porcelain strength.

The reason that the resistance of the units shown in figure 10 to impact was not stated in inch pounds is because it has been found that variations in the rigidity with which the units are held materially affects the results obtained from any type of impact test. Thus, to be comparative, tests on different insulators must be run in the same or similar equipment. To give some idea of the shock resisting ability mentioned by Smith, it has been found that the insulators shown in figure 10 may be influenced in their ability to withstand mechanical shocks as much as 300 per cent by adjustment of the initial state of tension or compression in the surface.

Smith is quite correct in certain of his criticisms as outlined in his numbered paragraphs at the conclusion of his discussion. Necessarily in applying the principles which have been outlined we must assume that the manufacturing control is of such a character as to make it possible to produce nonporous porcelain free from firing strains. With modern equipment there is no doubt but that this is possible. As a matter of fact our experience indicates that overfiring or bloating of the ware has been the source of far more trouble in the past than slight porosity due to under firing. To safeguard against both these undesirable conditions, and as a measure of the exactness of the factory control, we have adopted as routine, in addition to the standard AIEE tests, much more rigorous checks. These fortunately enable us to assume rightly that the more obvious factors are controlled. Granted this, it is believed that the surface condition of the porcelain is of outstanding importance as a gauge of the service life of the units.

The control of this one factor materially raises the duration strength of insulators, markedly increases their ability to withstand mechanical shocks, and, by the same token, makes a porcelain capable of standing more severe thermal shocks. Because this effect is not obvious it has, and is in some cases, being neglected as analyses on relatively modern insulators indicate.

The Qualities of Incandescent Lamps

Discussion and author's closure of a paper by P. S. Millar published in the May 1936 issue, pages 516–23, and presented for oral discussion at the illumination session of the AIEE summer convention, Pasadena, Calif., June 25, 1936.

J. Franklin Meyer (National Bureau of Standards, Washington, D. C.): Readers of P. S. Millar's interesting paper may be further interested in a brief description of the methods of application of the Federal specification for large tungsten-filament incandescent electric lamps, referred to in the paper as "the specification."*

Annual contracts for the supply of incandescent lamps to the departments and independent establishments of the Federal government are awarded after public advertisements for bids by the Procurement Division, Branch of Supply of the Treasury Department, but a current contractor or a prospective contractor (bidder) must qualify before his bid to supply lamps for the coming contract period will be considered by the Procurement Division. In accordance with the terms of the specification:

1. A current contractor is considered as qualified to bid on a new contract for the ensuing contract period, if the weighted average life of all of said contractor's large lamps, inspected and tested by the National Bureau of Standards, during the first 8 months of the annual contract, does not fall below the weighted average of the rated lives of the lamps tested. A life tolerance, depending upon the total number of lamps of each size tested, as set out in the specification, is applied, and the weighted average life, both at the manufacturer's declared efficiencies and at specification efficiency for each size tested, must equal or exceed the rated average life of the lamps tested with the tolerance applied. Similarly the weighted average of lumens-per-watt at 70 per cent of rated life of the lamps tested, expressed as a percentage, individually for each size, shall not fall below 100 per cent by more than the specified tolerance for the total number of lamps tested.

2. A prospective bidder not already a contractor must make application to the procurement Division for a qualification test. Arrangements are then made through the National Bureau of Standards for an inspection of the bidder's plant and the selection of samples for photometric rating and life test. The Government inspector of lamps will inspect 1,200 lamps, each, of at least 9 sizes, labeled at 115 volts, and 1,200 labeled at 120 volts. From the rating-test lamps the inspector selects 20 lamps

* Federal Specification W-L-101b, February 5, 1935, with Amendment No. 1, May, 1936, entitled "Lamps; electric, incandescent, large, tungsten-filament" and 1937 Supplement to W-L-101b, may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 5 cents, each, per copy for the Specification and the Supplement. The amended specification and 1937 Supplement will be effective for government purchases on September 1, 1936, when 1937 contracts will go into effect.

(10 115-volt lamps and 10 120-volt lamps) for life test. These lamps are burned at the manufacturer's declared efficiency under carefully controlled voltage conditions.

The Procurement Division will consider the bid of the prospective contractor only if the weighted average life (both at the manufacturer's declared initial efficiency and at the initial efficiency listed in the current supplement to the specification) of all the sizes of lamps tested does not fall below the weighted average of the *rated* lives of the lamps tested. A tolerance depending upon the total number of lamps tested is applicable. The weighted average lumen-per-watt output at 70 per cent life is a further test criterion.

For the present contract period, called the 1936 contract, from July 1, 1935 to August 31, 1936, there are 4 contractors. At the end of May 1936, approximately 3,875,000 lamps had been inspected at the factories of the 4 contractors and more than 6,600 lamps had been life-tested in the laboratories of the National Bureau of Standards.

The annual supplement to the Federal specification for large lamps is revised each year, prior to the issuance of requests for bids by the Procurement Division, at a conference of contractors, representatives of the Procurement Division, and of the National Bureau of Standards. At this conference the changes in types of lamps, and increases in efficiencies, brought about by new developments in the art of lamp making, are considered with great care, and if found generally acceptable by the contractors and representatives of the Government, are incorporated in the supplement.

It must always be remembered that the Federal specification for incandescent lamps is strictly a purchase specification, designed primarily for the use of the Federal government. The manufacturer of incandescent lamps for general sale and use is not bound to comply with this specification except in so far as he supplies lamps to the Government. Many large purchasers of lamps, especially states and municipalities, specify that the lamps furnished them on contract must comply with the requirements of the Federal specification.

S. S. Mackeown (California Institute of Technology, Pasadena): About 2 years ago I had occasion to test a large number of imported lamps. Samples of all makes of imported lamps being sold in southern California were tested. The results of these tests were entirely consistent with the results described by P. S. Millar. Without exception these lamps were both poor in efficiency and had short life. The efficiency was so low that the lamps were worse than worthless in that during their life the purchaser would pay more for his light than if he had purchased standard lamps. This is true even though these imported lamps were given to the customer free.

It requires a relatively small decrease in efficiency to increase the power bill during the life of the lamp by more than the cost of the lamp. This is because the cost of power used by the lamp is large compared to the cost of the lamp. If we assume a rate of 5 cents per kilowatt-hour, a 60-watt lamp burning for 1,000 hours will consume $3 worth of electricity. Since the standard high quality lamp retails for 15 cents, a small decrease in efficiency can much more than offset the cost of the lamp. The fact that these imported lamps have both a poor efficiency and a short life could be traced to poor manufacturing methods.

Lamps are sold in such enormous quantities to the public who have not the equipment to measure the power consumed by these lamps or to measure the light emitted by these lamps, that it is a relatively simple matter to sell poor quality lamps which are in fact very expensive to operate. It seems to me, therefore, that Millar's paper, which is the first paper giving good quantitative data proving that the purchase of poor quality lamps is false economy, is very timely. The information in this paper justifies an electrical engineer in recommending the purchase of only high-quality lamps until such time as imported lamps approach the efficiency of standard domestic lamps. It would appear that the electrical engineer is performing a social duty by publishing the information obtained in this paper and thereby discouraging the purchase of low-quality imported lamps.

M. A. Babb (Duro-Test Corporation, New York, N. Y.): P. S. Millar has made an appraisal of the qualities of incandescent lamps comparing different lamps of American manufacture. The writer's relatively recent engineering work for one of the companies sponsoring the tests which the author used for a basis of comparison, and his present engineering work for a smaller American lamp organization qualify him to discuss, with a degree of accuracy, the author's paper. The author, through neglecting the actual cost of lamp failures in his mathematical analysis of the most economical lamp to use, has drawn conclusions which might be misleading to people less informed about lighting service costs.

If it can be proved mathematically that the 1,000-hour lamp is the best one for the general user, then it can be proved by the same method that many stores and most industrial plants should use longer life lamps for their general lighting to get their maximum lighting economy, due to their lower power rate. One standard life most economical for the average power rate with which general service lamps are used is not the most economical for the users having a low enough power rate. For this reason alone, which will be proved later in the discussion, it is fortunate for consumers that all brands of general service lamps have not the specified life of the 75 per cent stratum of lamps supplied for general lighting last year. From the test results given in the paper, brand *J*2 rather than the 1,000-hour lamps of the quality so highly recommended in Millar's paper, should possibly have been used in many more lighting installations during 1935 in order to get the maximum lighting economy.

To show this effect in a concise manner use the author's formula:

$$t = 5{,}800 \frac{p}{rw}$$

with the substitution for the value of p from the price of the lamp to the price of the lamp failure. The price of the lamp failure includes 2 things: the cost c of the lamp, and the expense e of the labor to replace the lamp including, among other factors, the expense of the lost production due to the interruption in lighting service. The formula then becomes

$$t = 5{,}800 \frac{(c + e)}{rw}$$

The term e can be put in this formula as it is the unit cost incurred with the price of the lamp every time the lamp has to be replaced.

The introduction of the value of e into the formula makes it applicable even to a hypothetical limit of the lamps being given away free of charge. In this imaginary case the lamps would have to burn a definite minimum time to be used economically for general continuous lighting. The terms 5,800, c, e, and w, change with the size of lamp being considered. Millar in discussing the optimum life of lamps chose the 60-watt size, which is the approximate average wattage of the general service lamps used in the United States. For purposes of this discussion his choice of 60 watts will be continued.

A large percentage of these general service lamps are used by consumers having a domestic rate. This rate averaged 5.04 cents per kilowatt-hour during 1935 in the United States. A smaller percentage of these lamps are used by consumers that have a lower rate. If a rate of 4.5 cents per kilowatt-hour is assumed to be the weighted average power cost used for general service lighting, then this value which agrees with the value Millar has used in his paper may be used as a base for an analytical comparison in this discussion.

The terms of $(c + e)/rw$ in the formula shows that the decrease in average power rate from year to year increases the most economical life lamp to use while the increase in the average wattage of lamps and their decrease in cost has the opposite effect. The value e remains approximately constant because of the nature of that expense, but is large enough with respect to c to be probably the most important of the 2 factors.

If we assume that the 1,000-hour lamp had the most economical life in 1935 in the average case, and use approximately the average general values for that year, the 75 per cent stratum of lamps set up the value of e for the general condition. Millar states when discussing the 1,000-hour convention for general lamps in this country, "It is the result of a consensus of judgment taking into account the wide variation in conditions encountered in the use of lamps." Substituting in the formula these assumed general values,

$$1{,}000 = \frac{5{,}800\,(15 + e)}{4.5\,(60)}$$

Therefore $e = 31.5$ cents.

A criterion for choosing between a 2,000-hour general service lamp and a 1,000-hour lamp is whether the most economical life to use is more or less than 1,500 hours. The value of e remains constant. The assumption might be made that 5 cents more has to be paid for the 2,000-hour lamp due, among other factors, to the effect of

lowering the production of the lamp manufacturer. Then for the limiting case

$$1{,}500 = \frac{5{,}800\ (20 + 31.5)}{r\ (60)}$$

and r becomes 3.32 instead of 4.5 cents.

Therefore, anyone paying less than 3.32 cents for a kilowatt-hour of energy might be wise to use 2,000-hour lamps, even though they pay 5 cents more for lamps than the prevailing price. They may still get the

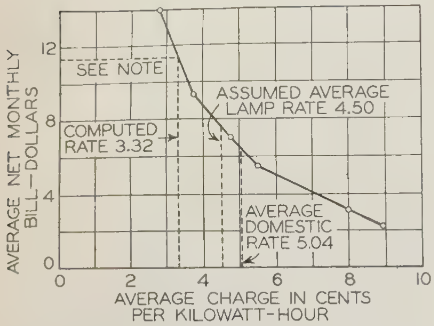


Fig. 1. Utility company electric rates in 1935

Average total for United States; number of communities 16,007

Note: Average consumers of lamps with electric bill over $11.50 per month may save by using 2,000-hour general service lamps rather than 1,000-hour lamps

most economical operation on a cost-per-lumen-hour basis for their particular rate. This class of consumer gets more light for his money if he uses longer life lamps with their necessary lower efficiency.

From figure 1 of this discussion giving the average utility company electric rates during 1935, it may be seen that the consumers paying a power bill of over $11.50 a month on the average, may use 2,000-hour general service lamps for greatest economy as 1,000-hour lamps probably are subspecification lamps for them. Thus there is a large field for the distribution of 2,000-hour general service lamps, which can be sold on the basis of maximum lighting service, for a particular rate classification.

The life-efficiency relation curve in the author's paper, appearing in figures 4 and 5 with respect to his plotted results, is applicable only if all the lamps tested have the same rigidity or, in other words, the same construction. If consumers had desired more supports in their general service lamps to gain strength and not have their lamps so fragile as the general service lamps put out by the 75 per cent stratum, the correct curve for their use would move to the left in these figures. As an example of what is meant: a 50-watt, *A*19 lamp requiring for its service a more rugged construction is given in the Federal specifications and if plotted in figure 5 would fall about where *N*2 is. It is specified to give an initial light output of 81.6 per cent of that of the 50-watt mill-type lamp.

The Federal specifications for government purchases of lamps may be effected by the qualities of the product and the standards of the general service lamps made by the largest lamp manufacturers. It is no criterion of the service required for the maximum economy at any particular power rate. No one standard can best supply each requirement, but there should be different lamp services offered, and the consumer should be educated to pick the one best suited to his needs.

It is well to mention, although it is not used in the above analysis, that the difference in initial light output between the 2,000-hour lamp and the 1,000-hour lamp with fewer supports is very small in terms of lighting service. L. V. James of the General Electric Company states: "The minimum steps in lighting intensity, given in foot-candles, required to produce an obvious and significant improvement in seeing are as follows:

1 2 5 10 20 50 100

These minimum steps take into account such factors as production, comfort, and eyesight conservation." As may be seen from his figures, the minimum percentage in light output to give any obvious lighting service change in seeing ability is 100 per cent. This difference between a 1,000-hour and 2,000-hour lamp of more rugged construction may be in the order of 15 per cent.

As an example of what service a small American lamp company can supply, there is such a lamp company that makes only 2,000-hour general service lamps. The lamps have more supports than the usual 1,000-hour lamps and tie wires are used to prevent the changing of position of the leads. The company has had to pioneer, in this country, by etching their lamps with the initial light output rating and hours of life as well as their wattage and voltage to prevent misunderstandings. The company makes their lamps to their own specifications and warrants them to live up to these specifications on a free replacement basis. A company selling lamps on such a basis has a much closer contact with its consumers. This helps the manufacturer to make lamps that better fill the users requirements. Such specifications are more serviceable for certain users of general service lamps than those which the government specifies for purchase by Federal bureaus. Such lamps cannot be compared, as the author has compared long and short life lamps in his paper, because the lamps are designed to fit a different requirement of service both in construction and economical life. The smaller American lamp companies can be very awake and sensitive to the economic requirements of its consumers.

References

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2. Utility Company Electric Rates, William M. Carpenter. Edison Electric Institute *Bulletin*, v. 3, November 1935.

3. Report of the Lamp Committee, N.E.L.A. Publ. No. 229, June 1932.

4. Lighting for Effective Seeing, L. V. James. Electrical Engineering, v. 52, August 1933, p. 543–6.

P. S. Millar: At the summer convention there was much discussion of this paper in addition to that represented by the 3 written discussions here printed. Of these, that by J. F. Meyer and that by S. S. Mackeown add pertinent information, which, however, is not of a nature to require any further comment. The discussion of M. A. Babb raises several interesting questions which it is desired to comment upon as follows:

The gist of Babb's discussion is that there is a place in American practice for a longer-lived lamp than that fitted to the generality of installations, and he suggests that such a place is found where power costs are very low. This may not be gainsaid, but lamps intended for general lighting purposes have to be designed for the generality of cases. If in any particular case a longer-lived lamp is deemed desirable, the important thing is to select inherently good lamps of highest available efficiency at the long life and not such inefficient lamps as he refers to in the designations *J*2 and *N*2. For example, with specification-quality lamps a 2,300-hour life, as typical of the 2 brands named, could be obtained with an efficiency 5 per cent higher than that of the lamps of brand *J*2.

Similarly, in the matter of special installations where there is a requirement for lamps of more than standard ruggedness, lamps having the highest available efficiency for that type of construction are likely to embody greatest economy to the user. It is not necessary to select relatively inefficient brands of lamps to secure either long life or greater ruggedness.

Engineering Education—

Opinions and Influencing Factors

Discussion and authors' closure of a paper by Morland King and O. W. Eshbach published in the June 1936 issue, pages 730–4, and presented for oral discussion at the education session of the AIEE summer convention, Pasadena, Calif., June 26, 1936.

A. Naeter (Oklahoma Agricultural and Mechanical College, Stillwater): In addition to the curriculum trends and changes that have been listed by the authors, there are certain others that merit attention. At the Society for the Promotion of Engineering Education convention in Madison, Wis., meeting concurrently with the AIEE convention in Pasadena, the writer discussed certain aspects of a new "general engineering curriculum" that was introduced at Oklahoma Agricultural and Mechanical College a year ago.

This new curriculum gives a more general technical training than is now offered in any one branch of engineering. It is a composite course of the basic essentials of civil, electrical, industrial, and mechanical engineering. It should meet the requirements of that large industrial operative and managerial group, as outlined by L. W. W. Morrow.

The graduate of this new course, after having become oriented, may then choose, if he desires to return to college for additional training, as his field of specialization the curriculum of any one of the 4 co-operating departments and receive his specialized degree in one year. The unique feature of this new course is that the student makes his choice of specialization after having received his degree, rather than in his senior year as is so common in general engineering

courses of this type. The difference is an important one.

This curriculum affords a certain number of electives. Cultural subjects are recommended, in accordance with the trend and requirements of the times.

The general engineering curriculum will not replace any existing departmental program of study. It has been in operation one year. Faculty, students and employers seem to be even more favorably impressed with its potential possibilities than they were a year ago.

Morland King and **O. W. Eshbach:** I am glad A. Naeter has called attention to their new general engineering course. It is one of a number of efforts to unify and correlate instruction in the sciences basic to engineering practice. As examples, somewhat similar attempts are being made at Stevens Institute of Technology (Hoboken, N. J.) and Swarthmore College (Swarthmore, Pa.), in the East. The idea is quite appealing to those who appreciate the value of a solid and broad foundation before specialization either in education or practice. It should also seem rational to many who have vainly tried to correlate industrial occupations with the traditional professional divisions of engineering.

I think for boys who plan for only 4 years of college it has 2 unfortunate handicaps, one is that the historical reputation of the name "general" is not conducive to academic and professional acceptability, and secondly the student has little natural incentive to associate, as he should, with one of the national engineering societies. It would be unfortunate if custom or tradition should seriously interfere with the development of sound technical education, yet these are factors which may be of considerable practical importance.

Cable Vibration—Methods of Measurement

Discussion and authors' closure of a paper by J. S. Carroll and J. A. Koontz, Jr., published in the May 1936 issue, pages 490–7, and presented for oral discussion at the conductor vibration session of the AIEE summer convention, Pasadena, Calif., June 23, 1936.

G. W. Stickley (Aluminum Company of America, Massena, N. Y.) and **R. G. Sturm** (nonmember; Aluminum Company of America, New Kensington, Pa.): The authors apparently have developed methods by which natural vibration of conductors can be duplicated electrically and by which the small amounts of energy in vibrating conductors can be measured. The method of energy measurement appears to be the best thus far published and makes possible a more thorough study of certain phases of the vibration problem. By the authors' method it is possible to study the energy dissipated by various types and designs of dampers, and the energy dissipated internally by conductors at various conditions of tension and end clamps.

In figure 5 of the paper it is interesting to observe that the typical energy—amplitude curves are at least in qualitative agreement with the data obtained analytically and from actual hysteresis loop measurements discussed in the paper by R. G. Sturm ("Vibration of Cables and Dampers," Electrical Engineering, volume 55, June 1936, pages 673–88).

W. B. Buchanan (Hydro-Electric Power Commission of Ontario, Toronto, Canada): The authors note that the vacuum-tube circuit would not deliver a sine wave of voltage to the driving coil. It would be interesting to learn if a detailed analysis was made as to the cause of the distortion introduced through the use of the exciting coil to determine whether this was due to the characteristics of the tubes or possibly to nonsinusoidal variation in amplitude of the conductor.

If for any reason the motion of the conductor should vary other than harmonically with time the nature of such variation might give some cue as to the stress changes actually taking place in the conductors. The rapid rise of power input with amplitude, particularly with the shorter wave lengths, prompts questions as to the nature of the losses being measured. This aspect is discussed further in connection with J. S. Carroll's paper (see page 1148).

J. S. Carroll and **J. A. Koontz, Jr.:** See discussion by J. S. Carroll, page 1149.

Vibration of Cables and Dampers

Discussion and author's closure of a paper by R. G. Sturm published in the May 1936 issue, pages 455–65, and presented for oral discussion at the conductor vibration session of the AIEE summer convention, Pasadena, Calif., June 23, 1936.

W. B. Buchanan (Hydro-Electric Power Commission of Ontario, Toronto): The author passes very rapidly from the concept of traveling waves to that of standing waves and, as a result, the dynamic effect of the former is obscured if not almost entirely neglected. Our experience indicates that standing waves cannot be set up on a flexible conductor except by a traveling wave method and all the losses which impede the propagation of the traveling waves must be overcome before their components succeed in establishing standing waves.

This neglect of dynamic effects raises the question as to just how closely the computation of the maximum stress by Sturm's method approaches the true value obtained when dynamic effects are included. One outstanding effect might be outlined as follows:

The dependence of the stresses on the stiffness of the conductor is pointed out, also that no satisfactory theoretical analysis can be completed thereon because of manufacturing variations. From our experience in testing with traveling waves, we are led to believe there is little or no loss in large-diameter conductors due to interstrand friction; also in testing festoon material at various tensions it apparently requires only a small fraction (for example, 10 per cent) of normal stringing tension to cause a 15-foot section to act as a rigid bar. It seems reasonable, therefore, to assume that with uniform tension the stranded conductor would be uniformly stiff throughout its length and bending at any point would be proportional to the moment at that point.

Suppose, however, a traveling wave is reflected at a point of support, the longitudinal component of the wave effecting momentarily a reduction of say from 5 to 10 per cent in tension. This might readily result in a comparative collapse of the stiffness of the conductor at the mouth of the clamp with a resulting bending far beyond what would be indicated on the assumption of uniform stiffness.

This offers a plausible explanation of the reason for certain apparently erratic results we have obtained when the bending stress at the clamp was excessive. Such cases where this curvature at the clamp was from 25 to 40 times that in mid-span have been difficult to duplicate and, in general, have not been usable as comparative figures.

The analysis by Sturm leading up to equation 33 indicates a phase of conditions involved in testing that has been impressed on us recently and will be discussed further in connection with J. S. Carroll's paper, namely, if additional energy be required to stretch a conductor under test, such a component is likely to be fairly well distributed throughout the conductor and offer no menace to its life but the energy loss which tends to dissipate itself within 1 or 2 inches of length at the clamp is in an entirely different class.

R. G. Sturm: Reports of observations in both field and laboratory by many observers indicate that the phenomenon of high-frequency vibration of cables caused by wind appears in actual conductors as a standing-wave phenomenon. While there appears to be some shifting of the node point, this amount of shift is not very great compared to the loop length in the steady state of vibration nor is the residual amplitude of vibration at the nominal node point of any significance when compared with the amplitude out in the center of the span.

The work described by J. S. Carroll and J. A. Koontz, Jr. ("Cable Vibration Methods of Measurement," Electrical Engineering, volume 55, May 1936, pages 490–493) is based upon the fact that transmission line vibration is essentially a standing wave phenomenon. The work described by J. S. Carroll ("Laboratory Studies of Conductor Vibration," Electrical Engineering, volume 55, May 1936, pages 543–547), which shows a very close agreement between behavior of the cables vibrated artificially on the basis that the vibration is a standing wave and the vibration of the same cable in the wind tunnel without any attempt to force standing waves, serves as evidence to show that an actual cable, when treated on the basis of the standing waves, is an excellent example to demonstrate the existence of actual waves in conductors. The fact that small traveling waves may be induced by tower vibration or periodic beats for adjacent spans has been recognized by careful observations on actual transmission lines and indicates that

at no time simple single or double traveling waves can exist. Therefore, a study of a single or double traveling wave of large amplitude has not been treated because it was considered irrelevant to the actual phenomenon of conductor breakage from high-frequency vibration.

Laboratory Studies of Conductor Vibration

Discussion and author's closure of a paper by J. S. Carroll published in the May 1936 issue, pages 543–7, and presented for oral discussion at the conductor vibration session of the AIEE summer convention, Pasadena, Calif., June 23, 1936.

G. W. Stickley (Aluminum Company of America, Massena, N. Y.) and **R. G. Sturm** (Aluminum Company of America, New Kensington, Pa.): Laboratory studies such as those described by J. S. Carroll provide a desired means of checking Bate's formula for the energy transmitted to a vibrating cable by the wind. They also make it possible to check Relf and Ower's formula in the practical range of conductor diameters.

The curves in figure 2 of the paper show that smaller amplitudes were obtained at higher wind velocities, but they also show that the corresponding loop lengths were shorter. When drawing conclusions from these curves, it should be remembered that the importance of these factors is that they affect stresses. The bending stresses which may produce fatigue failures are dependent upon both loop length and amplitude, and exist by virtue of the fact that conductors do have considerable rigidity which differs widely for different types.

L. C. Peskin (nonmember; American Steel and Wire Co., Worcester, Mass.): Although J. S. Carroll is to be commended for his contribution to the general knowledge of the fundamentals of conductor vibration due to transverse winds, it is essential that those vitally interested in this problem completely understand the significance of his tests and that these tests do not by themselves give any indication of the relative merits of the various types of cables tested. It is true that Carroll states that nothing in his paper is meant to show the advantages or disadvantages of the various cables used. Nevertheless, in their description of the apparatus used, J. S. Carroll and J. A. Koontz, Jr., state, without further explanation, that "Other things being equal, the cable requiring the greater amount of power to vibrate at a given frequency and amplitude would be the one best suited to withstand vibration in service, as the cable having the highest loss would vibrate at the least amplitude."

It must be stated at the outset that above all, the cable engineer is concerned with the magnitude of the stresses induced in the elements of the cable and that in the complex stranded conductors used for high-voltage transmission lines the stresses bear no simple relationship to the amplitude of vibration. Confining remarks to vibration at resonance rather than to forced vibrations, for only the former type of motion seems to be of practical importance in the case of vibration due to wind, it may be said that if 2 conductors apparently geometrically similar and equally stressed in stringing take different amounts of energy to maintain their maximum amplitude, it is only because the forces derived from the wind are different or the damping capacities of the structures differ. Now, not only is a larger applied force or small damping capacity sufficient to cause a larger amplitude of vibration at resonance, but, also, what is extremely important, a small flexural rigidity of the cable may cause extensive motion. It is this last quantity which bears the greatest relationship to the stresses in the cable, and, while it must of necessity influence Carroll's amplitude measurements, it is not explicitly discussed.

When the mechanical engineer compares 2 geometrically similar and homogeneous shafts of steel having different heat treatments for use as machine parts subject to resonant vibration, a measure of energy at resonance is sufficient, for under these circumstances the statement referred to by Carroll and Koontz is directly applicable. Here, in this simple structure, the deflection characteristics of the 2 shafts are the same and fully determined theoretically or experimentally, and the one having the lower damping capacity will undergo the greater amplitude of vibration at resonance corresponding to a higher stress in the metal. But, in the complicated structure used by the cable engineer, amplitude at resonance is insufficient by itself to reveal the stresses to which the individual elements of the conductor are being subjected.

One must submit each type of cable to a stress analysis as shown by R. M. Sturm ("Vibration of Cables and Dampers," Electrical Engineering, volume 55, May 1936, pages 455–65). Then, knowing the complete stress deflection characteristics of the conductor, measurements such as Carroll's of the relative amplitudes of vibration for given wind velocities can be of extreme importance in revealing the magnitude of the stresses which the cable elements will undergo in the field. If these stresses are beyond the endurance limit of the cable material, then fatigue failures may be expected.

From such analyses as made above, it is not difficult to see that of 2 cables of different damping characteristics showing unequal amplitudes of vibration at resonance, the one having the greater amplitude may actually be undergoing maximum stresses lower than those of the other cable because of a type of stranding reflected in a lower flexural rigidity. Only when the amplitude of vibration results in the short circuiting of adjacent conductors can it by itself be of any major importance. With a knowledge, however, of the flexural characteristics of the conductor, which are influenced by the manner and method of fabrication, resonance amplitude is useful for determining maximum stresses.

In connection with the extremely low energy values found at resonance, the work of Von Heydekampf and others (see ASTM *Proceedings* 1931) on measurement of damping capacity shows that extreme care must be exercised in using such methods as that of Carroll's. Losses of energy due to air friction and end effects, even with knife edges, can be appreciable. One wonders whether or not the lack of any effect on the measured power input for type *C* conductor, after segments were soldered, may not be due to external losses being of greater order of magnitude than the losses in the cable itself. Furthermore, it is unfortunate that Carroll does not show set of tests for the knife edge supports similar to those shown in figure 4, for such tests would have indicated to what extent he had eliminated the end losses.

W. B. Buchanan (Hydro-Electric Power Commission of Ontario, Toronto, Canada): There are so many interdependent variables in the problem of testing conductors and their susceptibility to being set in vibration by the wind, that it has been very difficult to obtain test data that are acceptable without some reservation. This applies particularly to such over-all performance tests as the measurement of losses, and with due appreciation of these difficulties the writer hesitates to criticize what is really quite a commendable piece of work. There are, however, some factors which appear to be rather important and which materially affect the accuracy of the results and their practical value. In his opening paragraph the author presents what might be regarded as a caution against any rigorous application of the data given.

The scheme is in effect a substitution method. The deduction is made that the energy taken from eddy currents of air as motive forces would be equal to the mechanical and electrical input necessary to give the same amplitude of vibration at any given frequency. There seems to be one objection to this conclusion which affects its validity for actual quantitative results.

The rate of energy loss for the 2 cases is not identical. In the first case the air resistance is in effect eliminated, in fact the force due to eddy currents might be regarded as a negative resistance. In the latter case the air resistance and inertia effect acts as a load and absorbs energy from the conductor. Since the quantity being measured is the force or energy from such eddy currents, the errors introduced are likely to be greater than the quantity it is desired to measure.

The writer has been interested in any scheme which gives promise of evaluating the loss in terms of respective components, more particularly for the following practical reason:

By the traveling wave method of test the loss per double-span cycle of wave travel for a given case was found to be 5.5 per cent in amplitude at each reflection point and 8 per cent for each 1,000 feet of conductor.

Considering that the criterion which determines whether vibrations are built up or not is based on the excess, if any, of energy input to losses, it is important to realize the nature of the losses and be assured as to what components of loss are at all times present. The loss at points of reflection appears to be generally fixed, and nonrecoverable. The loss throughout the span within a certain range or frequency appears to vary as the square of the amplitude or as the square of the velocity. This

suggests viscous or velocity damping or both, but thus far in unknown proportions. Should the velocity damping (by air) be appreciable under no-wind conditions, then a critical wind velocity over a large part of the span, setting up vibrations, would materially reduce the 8 per cent loss as noted. The practical result expected would be that for particularly severe exposures a greater amount of supplementary damping would be required than might be indicated by satisfactory performance on other apparently similar installations.

This interest in the nature of the losses led to an examination of the data submitted by the author to discover if possible the cause of differences in laws determining these losses, and resulted in the following observations:

Normally, the reduction in effective length of a conductor when vibrating is compensated for by a slight reduction in sag of the span and a slightly higher average tension. With shorter spans and still smaller sags, it must, therefore, take more power to build up waves to the same amplitude because of the greater variation of stress through which the material is worked. This feature was discussed by Sturm, but without direct application to these results.

Carroll notes that the loss in 2 loops in the 82-foot span was greater than the loss with 4 loops at the same amplitude and frequency. He questions terminal conditions, and while no doubt the terminal loss is a quite high percentage of the total loss in such short-span tests some difference in the variation in tension stresses and hence in stretching would also occur. Such conditions might also account for the rapid increase in power input with frequency or shorter-loop lengths and be materially affected by the elastic properties of the materials used.

J. S. Carroll: L. C. Peskin's discussion contributes some very helpful information to the subject of conductor vibration. With respect to further explanations concerning the quotation that Peskin makes from the J. S. Carroll and J. A. Koontz, Jr., paper, one definite fact should not be lost sight of. That is, the greater the amplitude of vibration, the greater is the amount of energy taken from the wind, and the greater the amount of energy taken from the wind, the greater will be the vibration. How far this will continue depends entirely upon the internal damping of the conductor. It is true that even though these amplitudes are of considerable magnitude, they may not be dangerous so far as overstresses in the cable are concerned. Fatigue tests alone can decide this question. To our knowledge operating experience has shown the best way to fight these problems of vibration in the field is to prevent the conductor from beginning to vibrate or restrict its vibration to a very small fraction of an inch.

To what extent flexural rigidity can affect amplitude measurements is not clear. With several of the conductors tested the form of the vibrating loop was checked and in every case was found to follow a sine wave as nearly as measurements could be made.

In the latter part of Peskin's discussion he uses the term "external losses" in connection with reference to the type *C* conductor after the segments were soldered together. The only one of these losses he mentions specifically is that of the knife edges. Since this paper was published these knife edge losses have been found to be less than one per cent of any of the losses shown for the type *C* conductor so that a variation of these losses could not have been of any importance. The wind losses would have been the same since the surface of the conductor was not altered. The frequency was set exactly the same for both cases.

One of the questions raised by W. B. Buchanan in his discussion is the matter of air damping. Since the publication of this paper, other conductors have been studied. One of these conductors have shown losses only 10 to 20 per cent of those for the conductors reported in the paper. This further bears out the author's statement that air damping is a small factor. The question was also raised with respect to the validity of measurements made on short spans. Recent measurements have shown that the loss on an 83.5-foot length is just half of that for a 167-foot length when the tension and frequency are the same, knife-edge supports being used in each case. Buchanan infers that with the short span the tension is appreciably increased by vibration. By actual measurement for amplitudes up to one inch and loop lengths of approximately 20 feet this change in tension is less than one per cent.

It is difficult to see just what relation the results obtained from traveling waves have to the results obtained from the standing waves. For all the records observed that have been taken in the field, there have been definite frequencies of vibration. Not necessarily single frequencies, but either single frequencies or a combination of one or more frequencies which in some cases causes beats and these beats are undoubtedly interpreted by some to be traveling waves. When the conductor is vibrated in the wind tunnel there is absolutely no evidence of any traveling waves along the conductor.

The author wishes to call attention to an error in figure 10, in which all amplitudes should be multiplied by one-half.

Cable and Damper Vibration Studies

Discussion and author's closure of a paper by L. A. Pipes published in the June 1936 issue, pages 600–14, and presented for oral discussion at the conductor vibration session of the AIEE summer convention, Pasadena, Calif., June 23, 1936.

G. W. Stickley (Aluminum Company of America, Massena, N. Y.) and **R. G. Sturm** (nonmember; Aluminum Company of America, New Kensington, Pa.): In the opening sentence of his paper, the author states that the subject of conductor vibration lends itself to a mathematical discussion if certain assumptions be made. Great care must be exercised in choosing the underlying bases of discussion in order that they may be compatible with facts. The author's description of a Stockbridge damper is quite inadequate for a mathematical discussion of the actual functioning of this device. Long experience has proven that this damper is only partially effective if the cantilever member is a rod instead of a stranded cable. Thus the author has overlooked the important hysteresis characteristics of the working member of the damper. The size and proportions of the damper weights must vary with the size of the conductor. The distance between the weights of a damper, even for a very large conductor, is less than 2 feet, instead of being 5 feet as stated by the author.

The approximate equivalent type of a Stockbridge damper (weight and damping springs) analyzed by the author has only one natural frequency, whereas it has been demonstrated that the standard Stockbridge damper has 2 natural frequencies within the range of frequencies which occur in service.

All of these factors are of utmost importance in any adequate mathematical discussion of Stockbridge dampers.

W. B. Buchanan (Hydro-Electric Power Commission of Ontario, Toronto, Canada): The analysis by L. A. Pipes has been very interesting to the writer as it supplements mathematically the results contained in the paper referred to by the author.

Mathematical analysis by itself is under a handicap because the symbols give no sense of proportion but empirical data must be introduced to determine whether certain approximations would be justifiable or not. For this reason it is thought that some data relating to various points of interest mentioned by the author might be useful, and possibly valuable to other investigators.

Tests were made to determine the attenuation factor in a 650-foot span of 795,000-circular mil steel-reinforced aluminum cable at tensions between 2,400 and 6,800 pounds. Calculations were made from curvature records obtained by the traveling-wave method of test. The figures are as follows:

Tension, pounds	2,400	3,100	3,900
Attenuation factor	0.675	0.72	0.775
Tension, pounds	4,750	5,850	6,750
Attenuation factor	0.785	0.80	0.815

These data very closely approximate that given by the expression $F_a = (1-15.2/\sqrt{T})$ where F_a is the factor by which the value of the curvature at any instant is multiplied to determine its value one double-span cycle later and T is the tension of the conductor. This factor, however, involves 2 components; the loss due to reflection at supports, and the loss due to travel of the wave throughout the length of the conductor. Data from other tests indicated that at each reflection point there was a 5.5 per cent loss in amplitude at 5,800 pounds tension, and about 8 per cent per 1,000 feet of travel. These data are remarkably consistent with the damping term in equation 5 by Pipes when the difficulties involved in its determination are considered.

We have been interested in any means suggested that would indicate the magnitude of the losses taking place when testing by a traveling wave compared with the corresponding loss during standing-wave conditions. The exponent of the damping

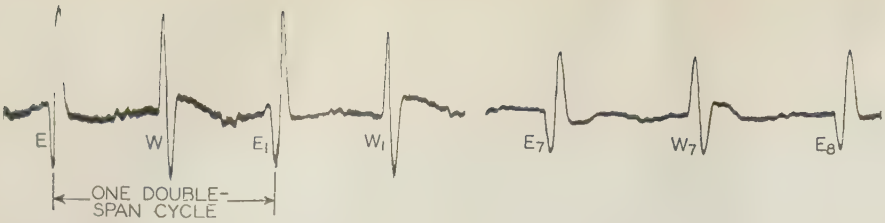


Fig. 1. Portions of curvature record of 5/16-inch 7-strand cable, showing no apparent distortion after 8 cycles of reflections

term in equation 5 may be altered in form, changing the distance S to the equivalent time, and assuming as noted that the velocity a equals $\sqrt{T/m}$, then

$$s = at$$

and

$$\frac{Rs}{2}\sqrt{\frac{1}{mT}} \text{ becomes } \frac{Rt}{2}\cdot\sqrt{\frac{T}{m}}\sqrt{\frac{1}{mt}} = \frac{Rt}{2m}$$

and may be considered as identical with the corresponding expression in equation 6.

The application of a traveling wave for testing must inherently involve considerable distortion or, in terms of a Fourier series, the wave must consist of a number of harmonics covering a fairly wide band of frequencies. Such a gamut for instance might include a 100-foot wave (50-foot loop) and various harmonics up to the tenth. Any appreciable difference in the losses at the different frequencies should result in an alteration in the wave shape and hence the curvature record should not appear as a simple reduction in amplitude. As an experimental check, figure 1 of this discussion shows portions of the curvature record obtained while testing a 5/16-inch 7-strand crucible-steel ground cable at a tension of 1,000 pounds in an 800-foot span. Low loss is indicated because the conductor is small, but the important point to note is that there is no distortion apparent even after 8 complete cycles of reflections. This being the case, an attenuation factor obtained by this means should be generally applicable throughout the range of frequencies generally considered hazardous. It also serves to justify certain approximations made by Pipes when deleting the effect of higher frequencies from further consideration. It does not, however, indicate that abrupt impacts, such as hammer blows, may be used, in fact such modes of initiating the waves have so far been found to be of negligible value for reasons pointed out by the author.

The reflection factor is in general the most intriguing quantity, apparently the most difficult to analyze and involves the greatest hazard from the standpoint of fatigue. The general treatment by the author, covering also reactions at dampers and other attached masses, indicates how involved this problem may become.

Tests made by the traveling wave method indicate generally that the reflected components are of the same shape as the incident wave at the wave lengths usually employed. Occasionally, however, there is distortion and records have been obtained where the distortion introduced by reflection at one end of the span was corrected or compensated for by the distortion due to reflection from the other end of the same span so that after passing over 2 span lengths and undergoing 2 reflections the wave shape was approximately of its original form.

During the early stages of development of this method of test it was found necessary to separate the reflection and attenuation factors, and a series of tests were made which indicated that they varied in practically the same manner with variation in tension. Hence when it was later determined that the attenuation factor had the form $F_a = 1 - \frac{K_a}{\sqrt{T}}$, it was assumed that a similar formula, for example, $F_r = 1 - \frac{K_r}{\sqrt{T}}$, should apply for the reflection factor for the masses involved in the same set of tests. This formula does not look exactly like that given by the author in equation 20a but possibly the differences may be more apparent than real over the range of frequencies used.

R. W. Sorensen (California Institute of Technology, Pasadena): The theoretical analysis of damper and conductor vibration presented by L. A. Pipes is indeed most timely in that he has set up so definitely a fundamental analysis which can serve as a starting point to which such modifications of an empirical nature as are dictated by laboratory experiments may be added.

In view of the strictly fundamental and theoretical nature of the paper, which, of course, cannot include all the modifying circumstances until much greater knowledge than we have at present concerning vibration is available, there will be many comments such as have been given in this discussion concerning the omission of certain important factors. In my opinion, however, this situation does not reduce to any extent the value of the paper even though the equations used do not account for all the characteristics which govern vibration, one of which I should like to mention; namely, the metallurgy of the conductor itself as related to the ability of the conductor to resist or attenuate vibrations. I call attention to this factor because in so far as I can determine our knowledge of handling conductor materials to date does not include information as to just why some conductors by their very structure seem to resist and/or attenuate vibrations much more than other conductors which to all outward appearances seem to be of the same material and design.

For example, I have recently had occasion to examine 2 pieces of conductor, both made of the same material, which do not differ greatly in tensile strength, but which have very different vibration characteristics. For example, the harder conductor which seemingly should vibrate longer than the slightly softer one, when set in vibration, does not do so.

As a result of this experience, I am inclined to think research on the conductor material itself would be valuable in teaching us how we might develop conductors, using the same materials which are now in common use, which are inherently more resistent to influences which set up vibration than are our present conductors and which when once put into vibration have larger damping factors than do the conductors now used.

L. A. Pipes: G. W. Stickley and R. G. Sturm are quite justified in pointing out that I have not correctly analyzed a Stockbridge damper. The damper analyzed in my paper is a simplified damper having but a single degree of freedom instead of 2 degrees. My simplified analysis, however, was for the purpose of showing the influence of resonance phenomena in the effectiveness of the simplest type of damper and a consideration of the factors affecting resonance in an adequate design. Instead of adopting the hysteresis characteristics of the working member, I have lumped the damping effects into a viscous damping coefficient. In the steady state, this is equivalent to a hysteresis damping. (See A. L. Kimball, "Vibration Prevention in Engineering," J. Wiley and Sons.)

Obviously the statement concerning the distance between weights is an error. In the original draft of the paper it was mentioned that the dampers are usually suspended about 5 feet from the supports and, in condensing the paper, this error was introduced.

The remarkably consistent results between experimental research conducted to determine the attenuation of traveling waves and a theoretical consideration which lumps the energy absorbing properties of the conductor into a viscous damping term, show that this assumed law of damping cannot be far in error.

As W. B. Buchanan points out, if the damping term in equation 5 be considered from the point of view of equivalent time, it is seen to be identical with the standing wave damping term in equation 6. This should furnish a link between standing-wave measurements of attenuation and traveling-wave measurements, assuming that the law of damping is correct.

The absence of distortion in a traveling wave containing moderately high harmonics is another experimental correlation of the theory presented.

With regard to the reflection factors, it may be seen that the extreme complexity of of the general expressions makes their use difficult unless supplemented with actual values. If the quantities in equation 20a be determined, it may be that this complicated expression might be reducible to Buchanan's empirical formula.

As R. W. Sorensen points out, further experimental study is essential before a more complete and correct theory of conductor vibration may be established. At present, it would seem that a measurement of the energy loss per cycle of various conductors of different materials would be a contribution of great importance.

The Young Engineer Under Changing Conditions

Discussion and author's closure of a paper by R. E. Hellmund published in the April 1936 issue, pages 329–34, and presented for oral discussion at the education session of the AIEE summer convention, Pasadena, Calif., June 26, 1936.

L. A. Doggett (The Pennsylvania State College): Approximately 75 per cent of the papers referred to at the end of R. E. Hellmund's article are by educators or by authors who have been educators. One of the prime objectives of the AIEE committee on education is to get the opinions of men who have been practitioners all their lives. The only warrant for printing in ELECTRICAL ENGINEERING a paper by an educator on education is the avowed purpose of drawing out discussion on the part of the practicing engineers.

Last year in this quest for views of men in practice, we were fairly successful. We are very fortunate this year in having a paper by Mr. Hellmund, a man who all his life has been a practicing engineer and one who has followed closely the papers and discussions of the AIEE educational committee sessions. We educators do not necessarily need to agree with all that is said by our friends in industrial life; a careful consideration of their opinions, however, should prevent the type of in-breeding which may occur when 100 per cent of the papers and discussions are by educators.

For example, there has been a pretty definite demand by practitioners for more economics; Hellmund reiterates this demand. I think they want more of what is sometimes called "enterprise-economics." As a whole, the technical schools have not satisfactorily met this demand, because they have too often provided something very different, that is, courses in "classical economic theory." I believe it is up to the practicing engineers to write the specifications for the type of economics course that they believe should be given. These specifications should not only define the type of course, but in addition give certain necessary qualifications of the instructor. The economics department, a service department, from the point of view of the electrical engineering department, may then be approached and a specific responsibility presented to them.

I hope that Hellmund in his closure will favor us with brief specifications of the type of economics he has in mind.

G. E. Doan (Lehigh University, Bethlehem, Pa.): R. E. Hellmund has written a thoughtful and mature account of the training and education which a young engineer finds most useful after he is launched in an industrial career. Engineering educators will agree with almost all that Hellmund says.

I agree that engineers could not have prevented the boom and following depression.

I agree that the engineers must continue to reduce costs and increase production, whatever may be the business cycle. He must do more and better engineering in order to "raise the engineering profession to a higher level in society." This view leads Hellmund to defend the traditional engineering education against those modern tendencies toward a more liberalized course of study which appear to grow in strength among engineering educators today. In support of this conservative view, he says, "In judging a physician or a lawyer, we do so by the ability of each within his own profession, and in evaluating the standing of either of these professions in society, we naturally do it by the accomplishments of the profession as a whole." Immediately one is prompted to ask Hellmund why these physicians and lawyers should waste 4 years getting a bachelor of arts degree as they do, rather than to begin the study of medicine and law as soon as they are out of high school, as the engineers do. Evidently it is considered necessary for a physician or lawyer to understand humanity in order to be of greatest use to society. It seems to me that if engineers are to serve humanity best, they too must have a fairly good understanding of humanity, just as surely as the lawyers and physicians must.

And, in fact, Hellmund agrees that the understanding of human life is a necessary part of an engineer's equipment, and that he needs it in sales, in public relations, and in industrial design. Even in the strictly technical aspects of industry, this broader understanding of human nature is necessary, for Hellmund says (p. 330): "With the increase in industrial organizations and the necessary specialization and departmentalization, work cannot, be performed effectively without a thorough knowledge of human nature. This . . . has been emphasized by the depression. Whenever reductions in force were necessary, the deciding factor in the release of one rather than another (employee) was frequently some personal shortcoming rather than a lack of technical ability."

Again and again Hellmund cautions the young engineer not to specialize too far, to preserve "a balance between his personal characteristics and his engineering activities, . . . the absolute necessity for striking the proper balance in everything."

Thus Hellmund and I agree entirely in principle. The engineer must understand human life if he is to help it much, if he is to raise the level of his profession, if he is to serve industry well, in fact, if he is to hold his job when a weeding out of personnel comes.

We are in full and firm agreement that the engineer must understand the foundation of human society, but Hellmund believes that psychology and economics are all he needs to round out this human understanding, and this is where we reach the end of our agreement. Fervently I wish such a simple formula were effective, but I know there is no such panacea for ignorance. How can our times possibly be understood without knowledge of the historical past which was prologue to it? How will a salesman or an administrator understand the workings of the human mind in terms of modern psychological complexes as well without the greatest students of the mind the world has ever known—Shakespeare and Aristotle and Jesus of Nazareth—as with it? That means literature and philosophy as well as history. How understand man at all until you see him as the biologist does, coming up from the apes, surviving nature, choosing a mate, and re-peopling the earth according to the laws of heredity?

Science has found so many short cuts in industrial life, why should it not find a short cut to human understanding, the engineer asks? It may be possible for Science to find such a short cut, but as an engineer and as a man, I know it hasn't yet found it, neither in psychology nor in economics. The physician and lawyer know it too.

But let us not hastily conclude that a bachelor of arts course gives this understanding to all who go through it. Some men attain it without ever going to college; they are specially gifted persons. Thousands, conversely take bachelor of arts degrees and gain no semblance of human understanding or liberal education; they are incapable of acquiring it. However, between these 2 extremes there is a large group of men for whom development of broad views and long vision and understanding of the human scene is possible. It is upon the men of this middle group that the future of civilization rests, whether they be engineers or lawyers or physicians. For them the liberalizing studies will not be just so much time wasted.

Good engineers we must have, but they cannot be mere technical hirelings and "pale mechanicians." Perhaps Hellmund speaks of raising the level of the engineering profession because the great majority of engineers in the past have been trained as technicians instead of being educated as engineers. However, there is no short cut to a liberal education, especially not under the mass-education system of today.

What, then, should be done? Are 6 years necessary to educate an engineer before he is ready for industry? I have given it careful study and I think not. If the excessive specialization such, for example, as the "engineering of transmission projects" which Hellmund mentions, are eliminated from the present-day 4-year engineering course, there will be ample room in 4 years both for a thorough foundation in science and for the elements of a liberal education. Specialization can come later, either in the industrial evening courses or in post-graduate university work. Such specialization will then not be premature and wrongly chosen as it is in the case of $^3/_4$ of the undergraduates of today.

Industry as a whole would prefer engineering graduates of this well-rounded type instead of the premature and narrow specialists which it now receives, and industry has said so in no uncertain terms. Since both the scholars and the industrial leaders are agreed in this matter, the trend is likely to develop rather rapidly. I feel sure Hellmund will welcome the change when it comes.

C. C. Williams (nonmember; Lehigh University, Bethlehem, Pa.): This paper is particularly helpful in engineering education in that it is from the pen of a practical engineer of unusual discernment and industrial experience. It gives added emphasis to the growing belief that technical engineering must be set in the social and economic structure with a surrounding of related accessory preparation and that engineering colleges must furnish that

accessory preparation. The immediate concern is to provide specific procedures which will accomplish the training so generally agreed upon as desirable.

While recognizing the psychological element desirable in this supplementary preparation, I am not so sanguine as is the author with regard to the results obtainable from including the usual elementary courses in psychology as a part of the educational background. The engineer's education might well be continued after college by means of systematic reading, correlating the material to his advancing stage of professional development in some such fashion as:

First 5 years, emphasis on technical material.

Second 5 years, emphasis on accounting and business methods.

Third 5 years, emphasis on general economics.

Fourth 5 years, emphasis on finance and credit.

Fifth 5 years, emphasis on general culture and psychology.

On the basis of observed careers of engineering graduates, some such order of intellectual development seems to fit the needs of the average, both in his professional career and in his enjoyment of life. Engineering education can no longer be restricted to the 4 years in college, but must extend through the entire period of professional advancement. For the talented, a period of graduate study will be found advantageous, but for the majority, self-improvement will necessarily suffice. The college course, however, may properly take into account the intellectual progress that will be made subsequent to graduation and aid that progress by suitable perspective.

P. S. Biegler (University of Southern California, Los Angeles): It is a pleasure to endorse the suggestions of R. E. Hellmund My own experience in training young men in a community far from East Pittsburgh and in totally different environment leads me to the same general conclusions in regard to such matters as length of curriculum, post-college study, and content of the engineering courses. These same problems were discussed in my paper before the Society for the Promotion of Engineering Education published almost simultaneously with Hellmund's.

In metropolitan communities such as Los Angeles there is a very pronounced demand among the young engineers for formal courses in engineering and related subjects, and our experience in conducting classes for these men who have been in engineering work for a number of years is, indeed, gratifying. Men with some engineering background have splendid motivation for graduate work and a much better appreciation of the opportunity for guided study. Those young men not within reach of the metropolitan universities might well do this work through extension courses.

There has been some discussion of the importance of selecting the right man to teach English or engineering economy. It seems to me that this is by far the most important part of administering any curriculum. The best laid plans fizzle in the hands of the wrong teachers. Certainly the average undergraduate in engineering fails to appreciate the importance of the language and will not concern himself about it without an inspiring teacher. Likewise it is folly for one without a good engineering background to teach engineering economics. In fact, I think a foundation of experience in engineering work is essential to the teaching of all engineering work. While it is desirable for engineering teachers to have advanced degrees (especially from the university president's point of view) it seems to me much more important that they have close contact with engineering work.

While engineering colleges should not be carried away by the opinions of the industrialists, their ideas are of the utmost value to us and their co-operation in working out educational problems should be solicited.

R. E. Hellmund: The discussion contributed by Dean Biegler is very interesting in that it indicates that he, in a totally different environment, has reached conclusions practically identical with those presented in my paper. His paper presented before the Society for the Promotion of Engineering Education on the subject "Four-Year Curriculum Should Be Retained," to which he refers in his discussion, contains much that should be given serious consideration by those interested in the subject. Both his discussion and his paper bring out a number of points which I have not mentioned, but with which I am fully in accord. One of these points is that engineering education in the different institutions does not necessarily have to be uniform. I should like to amplify this by stating that it would be most unfortunate if there were no variations and I should like to further stress the statement in my paper that greater latitude should be given to the individual students in the same school. Progress can be made only by developing individualism, at least to a certain degree.

The study of the attitude of employers of engineers in southern California covered in Biegler's paper is of especial interest. I find the results of this study very much in accord with my own experience. Among other things, it is stated that in the opinion of the employers who answered the questionnaires, only about 30 per cent of their engineers would have benefited by more than 4 years of college work. It is an absolute fact that by far the largest percentage of engineering graduates enter work for which at least the purely technical content of the present 4-year courses is sufficient. Many examples of this might be mentioned, as, for instance, the design of conventional motors, the greater part of control apparatus, and many activities in industry which are more or less of a commercial nature. Even though it is true that in these activities a problem occasionally arises requiring the use of higher mathematics and similar subjects, the engineers are frequently unable to apply even the material acquired in the 4-year course because of lack of regular practice in these subjects. It would, therefore, be an economic waste to require engineers filling such positions to take a 5-year course. It is rather a general practice in industry to have within a group of engineers handling design and application one or 2 engineers of the more theoretical type for handling occasional difficult engineering problems; or again, in some of the larger organizations these problems are referred to separate groups of engineers theoretically inclined and trained or to research engineers.

C. C. Williams, while generally agreeing with the contents of my paper, states that he is not very sanguine about the results obtainable from a study of psychology. I am not particularly sanguine myself and in my paper state that a study of psychology will by no means overcome all shortcomings, but that it nevertheless seems to be the only practical means by which colleges can bring about improvement. His outline of systematic study after graduation is very interesting. However, I feel that the undergraduate curricula as well as any postgraduate educational program should be arranged in such a way that the various studies can be taken shortly before or at the time the student or engineer finds a need for them, and preferably not too long before he can make practical application of them. As an illustration: Some undergraduate curricula include, either as compulsory or optional, such subjects as finance and corporate structure. If it is considered that only a very small percentage of all students are ever called upon to handle matters of this kind and that even those who are will not have any use for them until they are well advanced in life, it will be seen that there is little justification for including these subjects in undergraduate programs. On the other hand, most engineers from the very beginning of their careers will find a knowledge of psychological principles and industrial economics very helpful, and it would therefore seem that these subjects should be included in the undergraduate program or at least very early in any postgraduate work. This latter consideration would call for some slight modifications in Williams' outline of study.

G. E. Doan's discussion is an enthusiastic plea for a well-rounded rather than too technical and undergraduate program. Among other things, he draws a comparison between the education of engineers and physicians and lawyers. In making such comparisons we should be careful to note the differences as well as the similarities in order to avoid wrong conclusions. For the sake of brevity, I can do no better than to refer again to Biegler's paper, wherein some of these differences are ably discussed. Doan cites many quotation from my paper and points out the necessity for the engineer's having a knowledge of human nature, but feels that this knowledge cannot be obtained without very extensive studies of history and literature. I am afraid that in the undergraduate program in engineering some shortcuts will have to be taken in acquiring a knowledge of human nature. I am aware that some industrialists have stressed rounded-out courses, but I am confident that but few of them would be willing to support their convictions to the extent of employing engineers who for an extended period would be unable to carry on engineering work of a character in keeping with the salaries paid to them. There is no difference in opinion regarding the final goal to be striven for, and my point of view differs from Doan's only in that I believe that much of the rounding-out work can and should be taken after graduation.

News

Of Institute and Related Activities

East Tennessee Section Organized

A petition for authorization to organize an East Tennessee Section of the AIEE, with approximately the eastern half of the state of Tennessee as its territory, was approved by the Institute's board of directors at its meeting held on May 25, 1936.

Leaders in the plan for the formation of the Section were Mark Eldredge of Memphis, vice president AIEE Southern District (4), Chase Hutchinson and Prof. J. G. Tarboux of Knoxville, and E. E. George of Chattanooga.

The organization meeting was held in Athens, Tenn., September 2, with an attendance of 33. Vice-President Eldredge served as temporary chairman, and the following officers were elected:

Chase Hutchinson, chairman
E. E. George, vice chairman
A. P. Farrow, Knoxville, secretary-treasurer

Dinner meetings of the Section were held in Knoxville on September 18, and at Chattanooga on September 19. At each meeting, President A. M. MacCutcheon gave the principal address on the subject "The Section's Part in Institute Activities," and National Secretary H. H. Henline spoke briefly upon Institute activities.

At the Knoxville meeting Chairman Hutchinson presided and Robert W. Lamar, vice president and general manager, Tennessee Public Service Company, introduced the speakers. The attendance was about 88. At the Chattanooga meeting Vice-Chairman George presided. Paul J. Kruesi, president, Southern Ferro Alloys Company, introduced President MacCutcheon, and Chairman Hutchinson introduced the National secretary. The attendance was 41.

The new Section was commended in the highest terms by the national officers for the attendance and enthusiasm exhibited at the 2 meetings.

Second International Congress on Testing Materials. According to a preliminary notice received from the International Association for Testing Materials, a second international congress will be held by that association in London, England, April 19–24, 1937. The stipulated object of these congresses is to obtain international co-operation in the study of materials and their testing, and to provide facilities for the exchange of views, experience, and knowledge with regard to all matters connected with this subject. The subjects selected for discussion at the second congress are divided into 4 groups dealing respectively with metals, inorganic materials, organic materials, and subjects of general importance. Further information may be obtained from the honorary secretary of the congress, K. Headlam-Morley, at the offices of the British committee, the International Association for Testing Materials, 28 Victoria Street, London, S.W.1.

Dallas Meeting Program Complete

All is in readiness for the meeting of the South West District of the AIEE to be held from Monday to Wednesday, October 26–28, 1936, at Dallas, Texas. Headquarters will be in the Adolphus Hotel.

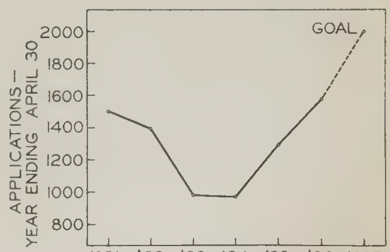
The committee has arranged an excellent program consisting of 5 technical sessions, 2 student sessions, several luncheon meetings, a dinner-dance, inspection trips, and entertainment for the visiting women. The program has been co-ordinated so that there will be special opportunity to see some of the features of the $25,000,000 Texas Centennial Central Exposition. Those attending the meeting may wish to attend also the Fort Worth Frontier Centennial, which comprises a variety of spectacular entertainment features. Fort Worth is only some 35 miles from Dallas. For a more complete account of the meeting, see the announcement and program in ELECTRICAL ENGINEERING, September 1936 issue, pages 1040–1. The program as given on page 1041 is complete with one slight change: The luncheon meeting of the District executive committee originally scheduled for 12:15 p.m., Tuesday, October 27, will be held on the following day, Wednesday, October 28 at 12:15 p.m.

Here is an opportunity to attend the South West District meeting and also to visit Dallas and see the Centennial. A large attendance is expected. The committee wishes especially to urge those who will attend to do so for the full duration of the meeting in order not to miss the opening session on Monday morning or the closing session on Wednesday afternoon.

Michigan College of Mining and Technology Holds Semicentennial Celebration. During the first week of August 1936, the Michigan College of Mining and Technology, Houghton, held a 3-day semicentennial celebration. One of the outstanding events was the formal inauguration of President Grover C. Dillman, who succeeded W. O. Hotchkiss, now president of Rensselaer Polytechnic Institute, Troy, N. Y. The AIEE was represented at the celebration by Prof. J. F. H. Douglas (A'20, M'35) of Marquette University, Milwaukee, Wis., past-chairman of the AIEE Milwaukee Section.

Membership—

Mr. Institute Member:



The upturn in this curve of yearly applications for AIEE membership is largely due to the help you have given your committees. *Please keep it going up* by boosting the Institute to those who you believe should be members and by giving their names to the chairman of your Section membership committee.

We have set as a goal 2,000 Applications by May 1, 1937. The committees are being organized for a big year's work. With your help *we will be successful!*

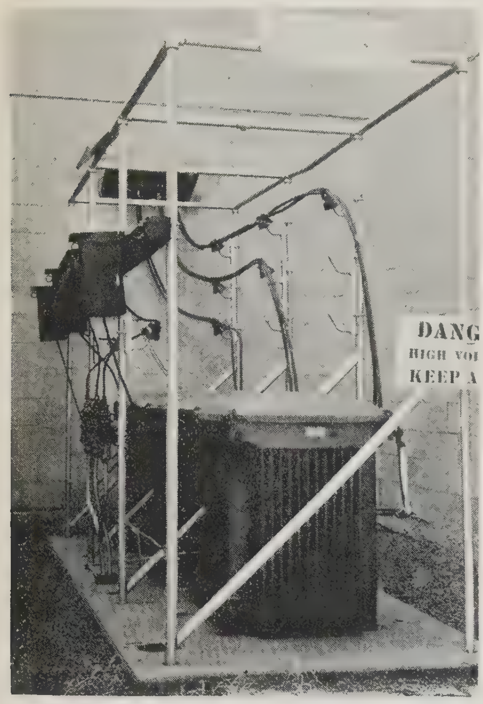
Assistant Chairman, National Membership Committee

Gaston Plante Medal to Be Awarded June 1937

The first award of the Gaston Plante Medal, recently established by the Societe Française des Electriciens, is to be made in June 1937. As announced previously in ELECTRICAL ENGINEERING (February 1936 issue, page 213), the award will consist of a silver-gilt medal accompanied by a sum in cash of 4,000 francs. The award will be made triennially to a person, regardless of nationality, who makes an important contribution in the field of electric storage batteries, voltaic cells, or electrochemistry in general.

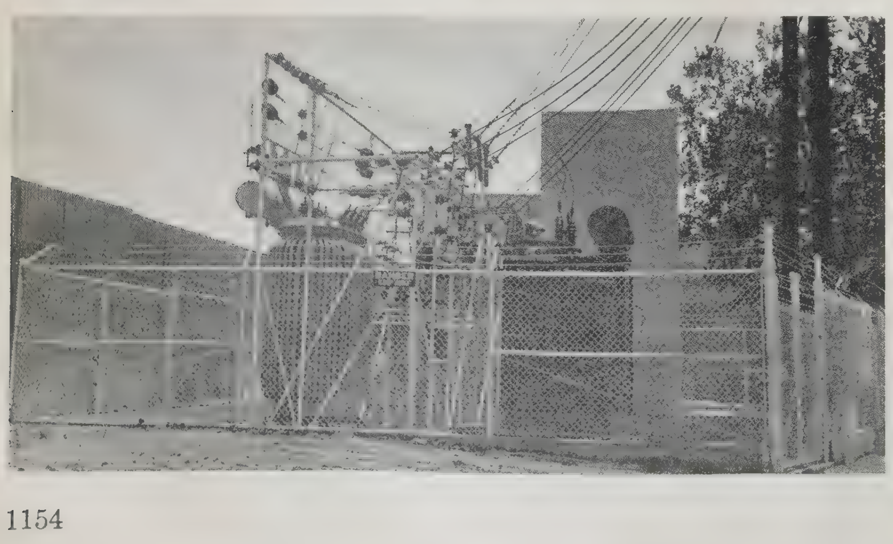
The electrotechnical societies and committees of each country may propose a candidate for the consideration of the commission of award, which consists of prominent members of the Société. Members of the AIEE are invited to submit suggestions of individuals who they consider worthy of this award to Institute headquarters not later than October 20, 1936. These suggestions will be considered by a special committee which will meet on that date. To act as this special committee, the AIEE board of directors has designated the following: President A. M. MacCutcheon; H. P. Charlesworth, chairman, Edison Medal committee; and N. E. Funk, chairman, Lamme Medal committee.

Meeting of American Institute of Physics. A joint meeting of the member societies of the American Institute of Physics will be held in New York, N. Y., October 29–31, 1936, at the time of the fifth anniversary of that organization. The meeting will consist partly of the regular sessions of the separate member societies and partly of sessions in which all the societies will participate jointly. The joint sessions will emphasize the applications of physics in the industrial world of today. Engineers and chemists, as well as non-scientists, are invited to attend this meeting. Further information may be obtained from the American Institute of Physics, 175 Fifth Avenue, New York, N. Y.



Power Supply for Texas Exposition

Electric power is supplied to the Texas Centennial Central Exposition at Dallas, from 2 13,200-volt distribution stations on opposite sides of the grounds which feed 38 "load center" stations distributed throughout the exposition area, over an underground distribution system. From these "load center" stations, power is distributed to the load, which is chiefly lighting, at 120/208 volts. One of the 2 substations is shown below; it contains one 3,000-kva 3-phase transformer and one 1,500-kva 3-phase unit. A typical "load center" station is shown at the left; this particular station consists of 3 100-kva single-phase 2,400-volt transformers with associated equipment. Those attending the Institute's South West District meeting to be held in Dallas October 26–28, may be interested to see these and other units of the distribution system on the centennial grounds.



ASTM Adopts New Tentative Standards

Among the new tentative standards for modifications of existing specifications and methods of test adopted by the American Society for Testing Materials at its annual meeting in Atlantic City, N. J., June 29–July 3, 1936, were the following:

1. Specifications for Hard Drawn Copper Alloy Wires for Electrical Conductors (*D*105-36*T*).
2. Method of Tests for Saponification Number of Electrical Insulating Oils (modified Baader method) (*D*438-36*T*).
3. Method of Testing Electrical Insulating Materials for Power Factor and Dielectric Constants (*D*150-36*T*).
4. Method of Test for Determining the Electrical Insulating Qualities of Plate (*D*273-36*T*).

Institute Members Invited to ASCE Sessions

Several symposia on various subjects have been scheduled for the fall meeting of American Society of Civil Engineers to be held October 13–16, 1936, at Pittsburgh, Pa. One of these deals with the subject of generation of energy. Papers are to be presented by engineers and economists on the following subjects: thermo-generation of energy, hydro-generation of energy, improvements in utilization of energy, cost of generation of energy, and economic aspects of energy generation.

Not only the engineering aspects of the subject are to be discussed, but also the economic and social aspects. Members of the AIEE have been invited to this and other sessions of the meeting.

AIME Meetings. The American Institute of Mining and Metallurgical Engineers has announced the following fall meetings:

Petroleum division, Fort Worth, Texas, October 8–9.
Institute of metals division, Cleveland, Ohio, October 20–22.
Iron and steel division, Cleveland, Ohio, October 20–22.
Coal division, Pittsburgh, Pa., October 20–21.
AIME general meeting, Mexico City, Mexico., November 9–15.

Future AIEE Meetings

South West District Meeting
Dallas, Texas, Oct. 26–28, 1936

Winter Convention
New York, N. Y., Jan. 25–29, 1937

North Eastern District Meeting
Buffalo, N. Y., May 1937

Summer Convention
Milwaukee, Wis., June 21–25, 1937

Pacific Coast Convention
Spokane, Wash., Date to be determined

Middle Eastern District Meeting
Akron, Ohio, Fall 1937

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Definition of "Inventing"

To the Editor:

Having read, recently, Rudolph Diesel's definition of "inventing" in its original German formulation, I thought that the interpretation of the most characteristic work of the engineer, by the designer of the Diesel engine, might be of some interest to the readers of ELECTRICAL ENGINEERING. The original definition and the English translation follow:

ORIGINAL

"Erfinden heisst, einen aus einer grossen Reihe von Irrtuemern herausgeschaelten richtigen Grundgedanken durch zahlreiche Misserfolge und Kompromisse hindurch zum praktischen Erfolg fuehren."

TRANSLATION

To "invent" means to free a basically sound principle from numerous immanent errors, and, after many failures and revisions, to realize its practical success.

Very truly yours,

LEE WALTHER (A'27, M'33)

Astoria, L. I., N. Y.

Zigzag Leakage

To the Editor:

In working with single and polyphase induction motors with skewed slots we frequently observe departures from the expected leakage reactances that cannot be accounted for by changes in any of the following factors:

Nonconcentric air gap (which tends to make machines noisy).
Skew (on the usual theory of Ball, Chapman, Dresse, and others).
Saturation (Norman).
Differential leakage (which should be small with short-circuited rotors and squirrel cage).
Zigzag leakage (as predicted by usual formulas).

Thus in the case of a repulsion-start induction motor of $^3/_4$-horsepower rating with 48–36 slots, 3 rotors were built, as nearly alike as possible except that the skews were made respectively, 0.5, 0.75, and 1.0 slots with respect to rotor slot pitch. The pull-out torques tested were, in the same order, 96, 92, and 83 ounce-feet. When the theory of Ball was applied in its most exact form, the results indicated that even for 1-bar skew the torque should differ from that for zero skew only by a negligible amount.

By the usual theories, such as those of C. A. Adams, E. Arnold, Herbert Vickers, and Chapman (Alger), there is no clue whereby the causes of this type of variation can be identified. In searching for possible causes of this behavior, it became clear that the presence of skew introduced a change in the differential leakage, which for the conditions here considered is small, and also introduced an axial component in the zigzag leakage, which may be of a value comparable with that of the circumferential component given by any of the formulas developed by the authorities mentioned. So far as known to us, this factor has not previously been considered.

The derivation of general formulas probably would be cumbersome and difficult. But it is relatively simple in any given case to obtain a ratio between the zigzag flux

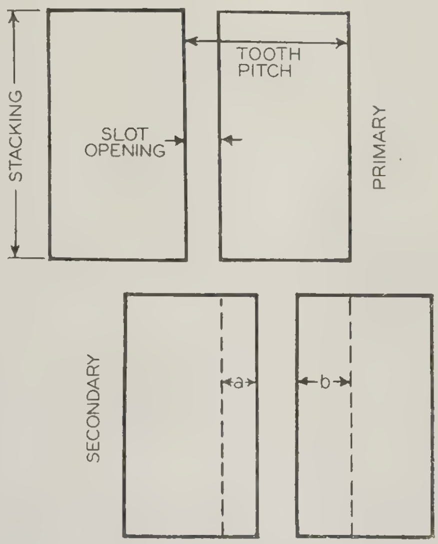


Fig. 1. Zero skew, equal number of stator and rotor slots

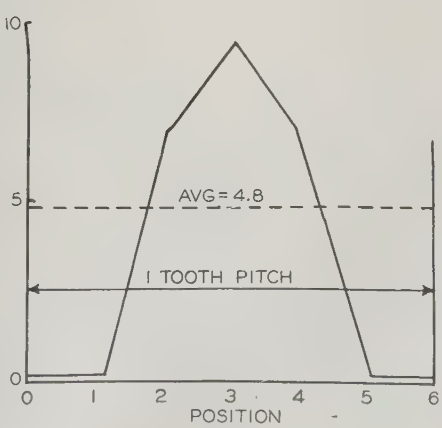


Fig. 2. Zigzag flux for zero skew

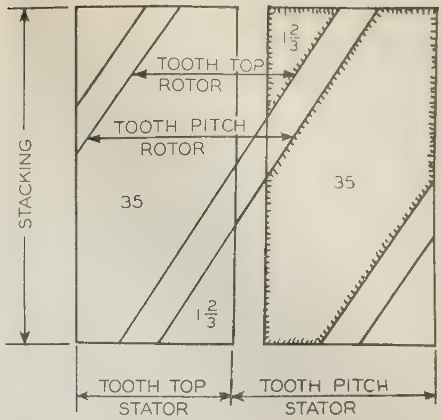


Fig. 3. One-bar skew, zigzag flux areas

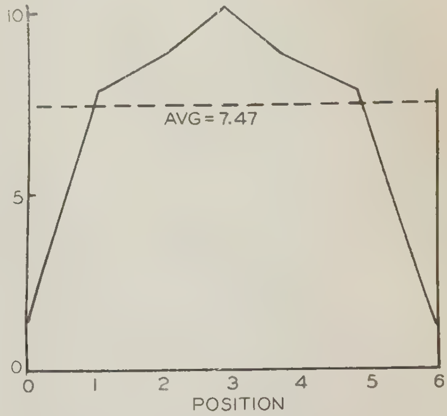


Fig. 4. Zigzag flux for 1-bar skew

with skew to that without skew. When this ratio is multiplied by the value obtained from one of the formulas mentioned, the corrected value of zigzag leakage, or permeance, may be obtained. Of course, it is possible also by a point-by-point process to obtain the result from fundamental considerations.

We give here the results of such an investigation for a case of 48:48 slots with zero, $^1/_2$-, 1-, $1^1/_2$-, and 2-bar skew on the rotor. The procedure is to draw the rotor in different positions and for each position to calculate the relative permeance in the path of the zigzag leakage flux. These points are plotted and the average over one tooth pitch obtained for both zero skew and the desired skew. The relative averages are the same for stator and rotor. Some writers (as, for instance, Adams) consider fringing, while others (Arnold) do not. The effects of core reluctance and air spaces between sheets are neglected.

The graphical work may be done in the following manner. Thus, in figure 1, the reluctance in the path of the zigzag leakage flux is the sum of that for the parts a and b, or

$$R = \frac{\delta}{aL} + \frac{\delta}{bL}$$

If the secondary is moved a step at a time so that the rotor covers the distance of one tooth pitch in 6 steps, and the results from the preceding formula for each step are plotted to an arbitrary scale, a result is obtained as shown in figure 2. The area under the curve in figure 2 is a measure of

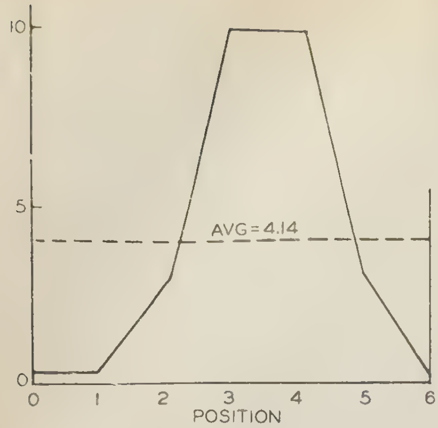


Fig. 5. Zigzag flux for 1/2-bar skew

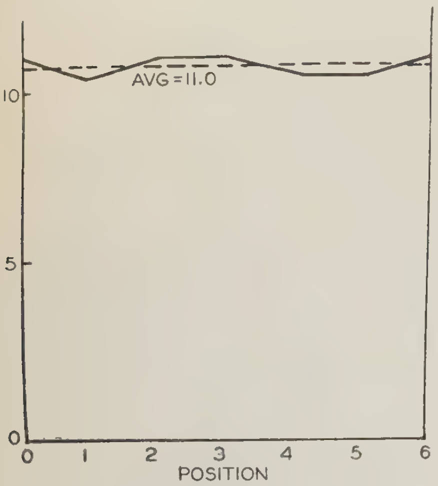


Fig. 6. Zigzag flux for 1 1/2-bar skew

the sum of the tangential and axial leakage fluxes.

Considering next the case of a 1-bar skew when stator and rotor teeth are alike in shape and number, the conditions for one position becomes as in figure 3. Here the relative reluctance in the same arbitrary units is

$$\left(\frac{1}{35}+\frac{1}{1^2/_3}\right)+\left(\frac{1}{35}+\frac{1}{1^2/_3}\right)=1.258$$

and the corresponding permeance = 1/1.258 = 0.796. When this process is carried through for 6 different positions and plotted, the results shown in figure 4 are obtained. This shows an appreciable increase.

$$\frac{\text{Zigzag flux, 1-bar skew}}{\text{Zigzag flux, 0 skew}}=\frac{7.47}{4.80}=1.56$$

Figures 5, 6, and 7 show the results for $^1/_2$-, $1^1/_2$-, and 2-bar skews, respectively. The corresponding ratios are

$$\frac{4.14}{4.80}=0.86 \qquad \frac{11}{4.8}=2.30 \qquad \frac{11.8}{14.8}=2.46$$

The figures thus show that, on the whole, the zigzag leakage increases with the skew. This increase in machine reactance is over and above that indicated by Ball. In computing the leakage reactance, the most exact procedure physically would be to compute

Slot separately for stator and rotor
Zigzag separately for stator and rotor
End separately for stator and rotor
Differential for stator

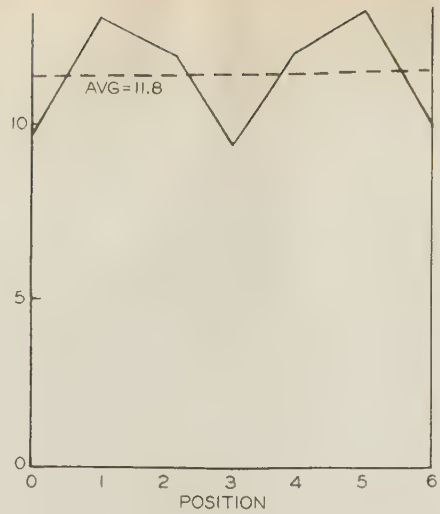


Fig. 7. Zigzag flux for 2-bar skew

by any of the recognized methods. The zigzag leakage reactance can then be corrected in the manner indicated. Strictly speaking, the end leakage will change somewhat also, as will the differential leakage. The latter change could be followed in some such manner as that indicated for zigzag leakage, but this is beyond the scope of the present effort.

At this stage the later work may be visualized from the equivalent network in combination with the equations of Ball to cover the effects of the change in mutual inductance caused by the introduction of skew.

When the number of stator and rotor teeth are unlike, the same general approach may be used. It is suggested that this work be extended in one of the following ways:

1. Further graphical work and the preparation of curves, for a representative variety of tooth and slot arrangements.

2. To cover the ground indicated by equivalent analytical work, excluding the Fourier series.

3. Same as item 2, but using the Fourier series.

Very truly yours,

A. F. Puchstein (A'20, M'27)
Chief Engineer

T. C. Lloyd (A'31)
Development Engineer

Robbins and Myers, Inc.,
Springfield, Ohio

Exploring the Atomic Nucleus

To the Editor:

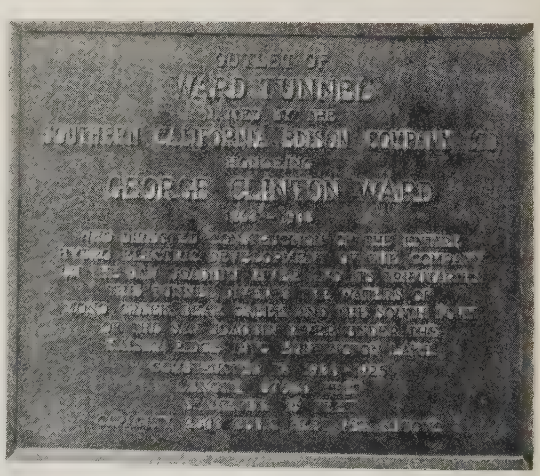
A recent publication has drawn attention to the fact that there is a certain amount of confusion in the literature on nuclear physics with respect to the difference between nuclear masses and atomic masses. Reading over my own paper, "Exploring the Atomic Nucleus," which was published in the July 1936 number of Electrical Engineering, pages 760–7, I find that the heading of table II will probably leave the reader in the same state of confusion. . . The heading of table II should be "Structures and Atomic Masses of Stable Nuclei."

Very truly yours,

Saul Dushman (A'13)
Assistant Director, Research Laboratory
General Electric Company,
Schenectady, N. Y.

Monument in Honor of Engineer Dedicated by Utility Company

"Outlet of
WARD TUNNEL
named by the
Southern California Edison Company, Ltd.
honoring
GEORGE CLINTON WARD
1863–1933
Who directed construction of the entire hydro electric development of the company on the San Joaquin River and its tributaries. This tunnel diverts the waters of Mono Creek, Bear Creek, and the South Fork of the San Joaquin River under the Kaiser Ridge into Huntington Lake.
Constructed in 1920–1925
Length 67,620 feet
Diameter 15 feet
Capacity 2,500 cubic feet per second"



To perpetuate the memory of its late president, G. C. Ward (M'24)* Southern California Edison Company officials and friends of the famous tunnel builder gathered August 26 on the shores of Huntington Lake in the California mountains to dedicate a monument of native granite bearing the above bronze plaque which records the new name of the record 13-mile Florence Lake Tunnel. This tunnel was built to direct water into Huntington Lake for successive use through the 400,000-kva Big Creek chain of high-head hydro electric plants built by Doctor Ward.

*Deceased Sept. 11, 1933: see Electrical Engineering, Oct. 1933.

Personal Items

I. M. STEIN (A'18, M'27) director of research, Leeds and Northrup Company, Philadelphia, Pa., has been appointed chairman of the Institute's committee on publication for the year 1936–37. Mr. Stein was born at Long Branch, N. J., March 20, 1894, and obtained his technical education from the New York Edison evening technical school, Columbia University extension course, and Fort Wayne Correspondence School. He was employed in the meter department of the New York (N. Y.) Edison Company in 1911, and the following year was transferred to the standardizing laboratory. During 1913 he was in charge of the rehabilitation work on instruments damaged in the flood at Dayton, Ohio, then returned to the test department of the Edison company. In 1916 he was made assistant foreman of the standardizing laboratory, and the following year was made foreman. During this time he was also engaged in work on protective relays. During 1918 he was senior inspector in the eastern department of the U.S. Signal Corps, and also worked as personal assistant to Thomas A. Edison in the development of submarine and airplane locating devices. He was engaged by the Leeds and Northrup Company as sales engineer in 1919, and 2 years later was given charge of general division sales. In 1924 he was made assistant sales manager, and in 1927 was given charge of development, engineering, production, publicity, and sales of combustion control apparatus. He is now director of research and a member of the executive committee of the company. Mr. Stein is the author of numerous technical articles. He has been a member of the Institute's publication committee since 1934, of the committee on co-ordination of Institute activities since 1933, and of the Sections committee since 1929, serving as chairman 1933–36. He served on the membership committee 1926–27 and 1931–33, and for 1936–37 has been appointed a member of the committees on technical program and award of Institute prizes. Among other organizations of which Mr. Stein is a member may be included the American Physical Society, American Chemical Society, American Electrochemical Society, Illuminating Engineering Society, Franklin Institute, and American Society for Testing Materials.

H. P. CHARLESWORTH (M'22, F'28, past-president) assistant chief engineer of the American Telephone and Telegraph Company, New York, N. Y., has been appointed chairman of the Institute's Edison Medal Committee for the year 1936–37. Mr. Charlesworth was born at Haverhill, Mass., April 7, 1882, and received the degree of bachelor of science at Massachusetts Institute of Technology in 1905, at which time he entered the employ of the American Telephone and Telegraph Company at Boston, Mass. For 2 years he was in the circuit-development division of the engineering department, then was transferred to the toll-traffic division when the department was moved to New York. He was assigned to special problem work until his appointment as equipment and transmission engineer in 1919. The following year he was appointed plant engineer, having general supervision over the entire plant engineering work of the Bell system. In 1928 he was elected vice president of the Bell Telephone Laboratories, Inc., resigning in 1933 to accept his present position. Mr. Charlesworth has been a member of the Edison Medal committee since 1929, and of the committee on Institute policy since 1933, serving as chairman of the latter 1933–35. He is now Institute representative on the John Fritz Medal board of award, United Engineering Trusteees, Inc., and American Standards Association board of directors. A past-chairman of the New York Section (1929), he has served on many other committees of the Institute, and was a manager 1924–27, vice president representing the New York City District 1930–32, and president 1932–33.

F. M. FARMER (A'02, F'13, director) vice president and chief engineer of the Electrical Testing Laboratories, Inc., New York, N. Y., has been appointed chairman of the Institute's committee on headquarters for the year 1936–37. Mr. Farmer was born at Ilion, N. Y., March 28, 1877, and was graduated from Cornell University in 1899. In 1903, after spending a year in the test department of the General Electric Company and $2^1/_2$ years in the inspection division of the U.S. Navy at the Brooklyn Navy Yard, he joined the staff of the Electrical Testing Laboratories, Inc. (then the Lamp Testing Bureau) in New York. In his extensive experience with electrical engineering materials and apparatus he has given special attention to electrical measurements, electrical insulating materials, and power cables, and has made numerous contributions to technical literature. He was a member of the Institute's committee on standards 1919–22 and 1923–36, of the committee on electric welding 1927–28 and 1930–31, and of the committee on award of Institute prizes, technical program committee, and executive committee 1933–36. He has been a member of the Edison Medal Committee since 1934, of the power transmission and distribution committee since 1920, and of the research committee since 1929 (chairman 1933–36). For the year 1936–37 Mr. Farmer has been appointed a member of the board of examiners, on which he served previously 1923–28. Since 1935 he has been Institute representative on the Engineering Foundation board and on the engineering societies monographs committee. Mr. Farmer is a past-president of the American Welding Society and of the American Society for Testing Materials, a fellow of the American Association for the Advancement of Science, and a member of the Institution of Electrical Engineers, The American Society of Mechanical Engineers, and other organizations, and has been active in the work of the American Standards Association.

W. B. KOUWENHOVEN (A'06, F'34, past vice president, director) professor of electrical engineering and assistant dean of engineering school, The Johns Hopkins University, Baltimore, Md., has been appointed chairman of the Institute's technical committee on research for the year 1936–37. Professor Kouwenhoven was born at Brooklyn, N. Y., January 13, 1886. He received the degree of electrical engineer from Brooklyn Polytechnic Institute in 1906, and that of mechanical engineer in 1907. Subsequently he received the diploma in engineering (1913) and the degree of doctor of engineering (1914) from the Karlsruhe Technische Hochschule, Baden, Germany. He was an assistant in physics and instructor in physics and electrical engineering at Brooklyn Polytechnic Institute from 1906 to 1910, and during 1913–14 was instructor in electrical engineering at Washington University, St. Louis, Mo. In 1914

I. M. STEIN

H. P. CHARLESWORTH

F. M. FARMER

W. B. KOUWENHOVEN

W. H. TIMBIE

G. A. KOSITZKY

N. E. FUNK

he joined the staff of The Johns Hopkins University as instructor, and in 1917 became associate in electrical engineering. On a leave of absence during 1919–20 he was engineering superintendent at the Winchester Repeating Arms Company, New Haven, Conn., and then returned to the university as associate professor in electrical engineering. His appointment to his present position was made in 1930. Professor Kouwenhoven has made numerous contributions to the literature of the Institute, and has given considerable study to electric shock. He was a vice president of the Institute representing the Middle Eastern District 1930–33, and is a director for the 1935–38 term. He has been a member of the research committee since 1933, and is also serving on the committees on Edison Medal, award of Institute prizes, safety codes, electrochemistry and electrometallurgy, and instruments and measurements. In the past he has served on several others, and has been active also in the work of the American Society for Testing Materials.

W. H. Timbie (A'10, F'24, past vice president) professor of electrical engineering, Massachusetts Institute of Technology, Cambridge, has been appointed chairman of the Institute's Sections committee for the year 1936–37. Professor Timbie was born at Pittsfield, Mass., August 20, 1877, and in 1901 was graduated from Williams College with the degree of bachelor of arts. During the next year he taught at Westerleigh Collegiate Institute, New Brighton, N. Y., and from 1902 to 1911 was instructor of industrial electricity at Pratt Institute, Brooklyn, N. Y. In 1911 he became head of the department of applied science at Wentworth Institute, Boston, Mass., where he remained until 1918, when he was editor-in-chief of the committee on education and special training of the War Department at Washington, D. C. In 1919 he joined the faculty of Massachusetts Institute of Technology as associate professor, his principal duties being the organizing and conducting of the co-operative course in electrical engineering. He was appointed professor of electrical engineering and industrial practice in 1923. Professor Timbie is the author of several books on electricity. He has been a member of the Institute's Sections committee since 1929, and is now a member of the committees on publication and co-ordination of Institute activities. He is also counselor of the Massachusetts Institute of Technology Branch, and is a past-chairman of the Boston Section. Other Institute committees on which he has served include general power applications (1924–30), education (1929–33), and student Branches (1925–28 and 1929–36; chairman 1929–33). During 1934–36 he was vice president representing the North East District. Among other societies of which he is a member are The American Society of Mechanical Engineers and the Society for the Promotion of Engineering Education.

G. A. Kositzky (M'22, F'29, past director) chief engineer, Ohio Bell Telephone Company, Cleveland, has been appointed chairman of the Institute's committee on membership for the year 1936–37. Mr. Kositzky was born at Yankton, S. D., April 20, 1879. He was educated at the University of Nebraska, which he attended for 4 years, and at Cornell University, which he attended for 2 years and from which he received the degree of mechanical engineer in electrical engineering in 1905. From then until 1909 he was employed by the New York and New Jersey Telephone Company at Brooklyn, N. Y., being promoted to the position of construction engineer in 1907. During 1910 he held the position of division plant engineer with the Pacific Telephone and Telegraph Company, San Francisco, Calif., and the following year became plant engineer for the Southwestern Bell Telephone Company at Kansas City and St. Louis, Mo. Later he was made general plant superintendent at Kansas City, and during 1917–19 was engaged in valuation work at St. Louis. In 1919 he accepted the position of chief engineer of the Central Union Telephone Company with headquarters at Chicago, Ill., and 2 years later undertook similar duties for the Ohio Bell Telephone Company, a position which he has held since. Mr. Kositzky served on the Institute's membership committee from 1923 to 1925, and has again been a member of it since 1935. He was a director 1932–36. Other committees on which he has served are general power applications (1925–26 and 1927–28), communication (1928–34; chairman 1929–31), meetings and papers, now called technical program (1929–31), and Edison Medal (1933–35). A past chairman of the Cleveland Section, he has also been active in other organizations, and was president of the Cleveland Engineering Society in 1928.

E. S. Lee (A'20, F'30, director) engineer in charge of the general engineering laboratory, General Electric Company, Schenectady, N. Y., has been appointed chairman of the Institute's committee on finance for the year 1936–37. Mr. Lee, who was born at Chicago, Ill., November 19, 1891, was graduated from the University of Illinois with the degree of bachelor of science in electrical engineering in 1913. He then became an instructor in electrical engineering at Union College, Schenectady, and while there earned the degree of master of science in electrical engineering, which he received in 1915. Since 1918 he has been affiliated continuously with the General Electric Company, becoming assistant engineer of the general engineering laboratory in 1928 and being appointed to his present position in 1931. Mr. Lee, who is a past-chairman of the Schenectady Section of the Institute, has served on many committees of the Institute, and has been a member of the finance committee since 1933. He has been a member of the committee on instruments and measurements since 1927 (chairman 1927–30), and of the membership (chairman 1933–36) and executive committees since 1933. For the year 1936–37 he has been appointed a member of the committee on co-ordination

E. S. LEE

of Institute activities, on which he served previously 1930–33, and of the headquarters committee, and also has been appointed Institute representative for the division of engineering and industrial research of the National Research Council. In 1933 he was elected a director of the Institute for a 4-year term. Numerous papers have been written by him, one describing membership activities of the Institute appearing in Electrical Engineering for September 1936, pages 954–5. Mr. Lee has also been active on committees of The American Society of Mechanical Engineers, American Society for Testing Materials, and American Standards Association.

N. E. Funk (A'07, F'34, director) vice president in charge of engineering, Philadelphia Electric Company, Philadelphia, Pa., has been appointed chairman of the Institute's committee on the Lamme Medal for the year 1936–37. Mr. Funk was born at Bloomsburg, Pa., November 4, 1883, and received the degree of electrical engineer from Lehigh University in 1905. For the

year 1906–07, following employment by the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa., and the New York Central Railroad Company, Berwick, Pa., he was associate professor of electrical machine design and mathematics at the Georgia School of Technology, Atlanta. From 1912 to 1914 he was employed by the Sterling Switchboard Company, Camden, N. J.; except for this period he has been associated with the Philadelphia Electric Company continuously since 1907 in various capacities. In 1926 he was appointed assistant chief engineer, and in 1928 was appointed chief engineer, later in the same year becoming assistant general manager. Since 1929 Mr. Funk has been vice president in charge of engineering. He is the author of several technical papers. From 1924 to 1933 he was a member of the Institute's committee on power generation, and during 1935–36 was a member of the committee on the code of principles of professional conduct. He has served on the Lamme Medal committee since 1935, on the committees on legislation affecting the engineering profession and transportation since 1934, and for the year 1936–37 has been appointed a member of the finance committee. Mr. Funk was elected a director of the Institute in 1934 for a 4-year term. He has been active in the work of the Association of Edison Illuminating Companies and the Edison Electric Institute, and is a member of The American Society of Mechanical Engineers and other organizations.

T. C. Lloyd (A'31) formerly associate professor of electrical engineering, Antioch College, Yellow Springs, Ohio, recently resigned to accept a position as development engineer for Robbins and Myers, Inc., Springfield, Ohio. Mr. Lloyd is a native (1901) of Emporium, Pa., and received the degree of bachelor of science in electrical engineering at Carnegie Institute of Technology in 1923. Following his graduation, he was employed as a sales engineer for the East Penn Electric Company, Pottsville, Pa., and remained with that company until he was appointed an instructor in electrical engineering at the University of West Virginia, Morgantown, in the following year. In 1925 he received a similar appointment to the faculty of Ohio State University, holding concurrently a part-time instructorship at Antioch College, and in 1929 was appointed associate professor in charge of electrical engineering at Antioch College. Mr. Lloyd is co-author, with A. F. Puchstein (A'20, M'27) of several textbooks on electrical engineering, the most recent being "Alternating Current Machines." He is also co-author of a paper "Capacitor Motors With Windings Not in Quadrature," published in Electrical Engineering for November 1935. He is a member of Eta Kappa Nu and the Society for the Promotion of Engineering Education.

H. V. Carpenter (A'03, F'13, past vice president) dean of engineering and director of enginering experimental station, State College of Washington, Pullman, has been appointed chairman of the Institute's committee on the code of principles of professional conduct for the year 1936–37. Dean Carpenter was born January 29, 1875, near Mt. Carroll, Ill. He was graduated from the University of Illinois in 1897 with the degree of bachelor of science in electrical engineering, and 2 years later received the degree of master of science in mathematics and physics. From 1897 to 1899 he was an assistant in physics at the university, and from 1899 to 1901 was an instructor. In January 1901 he became assistant professor of physics and electrical engineering at the State College of Washington, and 2 years later was appointed head of the department of mechanical and electrical engineering. Since 1917 he has held his present position as dean of engineering. Dean Carpenter is the author of various technical articles published by the Institute and elsewhere, and has made developments in electrical measuring instruments and also in water-wheel regulating devices. He is at present a member of the Institute's committee on education, on which he has served since 1931, and was vice president of the North West District 1930–32. Among the other societies of which he is a member are The American Society of Mechanical Engineers, Society for the Promotion of Engineering Education, American Association of University Professors, Tau Beta Pi, and Sigma Xi.

R. W. Sorensen (A'07, F'13, past vice president, director) professor of electrical engineering and head of the department of California Institute of Technology, Pasadena, has been appointed chairman of the Institute's committee on the economic status of the engineer for the year 1936–37. Professor Sorensen was born at Alta Vista, Kan., April 25, 1882, and received the degrees of bachelor of science in electrical engineering (1905) and electrical engineer (1928) from the University of Colorado. He was employed by the General Electric Company at Schenectady, N. Y., and Pittsfield, Mass., from 1905 until 1910, when he accepted the position of associate professor of electrical engineering at Throop Polytechnic Institute, which later became California Institute of Technology. He was appointed professor the following year. Since that time, in addition to his university work, Professor Sorensen has been engaged as a consultant on many problems. He has contributed to the literature of the Institute, and has served on the Institute's committees on research (1923–30), instruments and measurements (1927–30), and student Branches (1927–28), and as counselor of the California Institute of Technology Branch. Since 1934 he has served on the committee on education, of which he was a member from 1924 to 1928, and since 1933 on the Lamme Medal committee; he has been appointed a member of the committee on student Branches for the year 1936–37. Professor Sorensen was vice president of the Pacific District 1933–35, and has been elected a director of the Institute for the term 1936–40. Other societies of which he is a member include the Society for the Promotion of Engineering Education, American Association of University Professors, and Los Angeles Engineering Council.

R. J. Graf (A'11) first vice president, H. M. Byllesby and Company, Chicago, Ill., recently was elected president of the company. Mr. Graf is a native (1882) of Washington, D. C., and received his formal education in private schools in Washington. He was one of the original partners of the Byllesby Company when it was established in 1902, being appointed secretary and assistant treasurer at that time. He was appointed vice president and secretary in 1914 and first vice president in 1924. Mr. Graf has been associated with several important engineering enterprises in their financing and direction; he is a director of the Standard Gas and Electric Company and the Northern States Power Company.

W. J. Miller (A'19, M'26) formerly professor and head of the department of electrical engineering, University of North Carolina, Chapel Hill, recently resigned to become head of the department of electrical engineering at the University of Alabama, Tuscaloosa. Professor Miller was born 1893, in Bee County, Texas, and received the degrees of electrical engineer (1915) and master of science in electrical engineering (1922) at the University of Texas and Massachusetts Institute of Technology, respectively. In 1917 he was appointed an instructor on the electrical engineering staff of the University of Texas, being advanced later to the rank of assistant professor. Following a brief period as instructor in electrical engineering at Massachusetts Institute of Technology, Professor Miller became professor and head of the department of electrical engineering at the Oklahoma Agricultural and Mechanical College in 1921, where he remained until 1923. In that year he accepted a position as research


R. W. SORENSEN


R. J. GRAF


H. V. CARPENTER

engineer for the engineering experiment station of the University of Arkansas, remaining for 2 years before being appointed dean of engineering and professor of electrical engineering at the Texas Technological College, Lubbock. He was appointed to the faculty of the University of North Carolina in 1933.

J. F. Calvert (A'27, F'35) has left the engineering department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., to become a member of the faculty of the department of electrical engineering of Iowa State College at Ames. A native of Columbia, Mo. (October 14, 1898), Mr. Calvert graduated from the University of Missouri in 1922 with the degree of bachelor of science in engineering; took his "E.E." degree there in 1924, and was granted a master of science degree by the University of Pittsburgh in 1930. Immediately upon graduation in 1922, Mr. Calvert became affiliated with the Westinghouse company, first in preliminary work on the graduate student course, then (1923–27) in design work on large turbine generators. From 1927 to 1929 he was engaged in research on iron losses and allied subjects, from 1929 to 1932 in design work on large a-c generators, and from 1932 to 1935 in research on high-voltage insulation, lightning protection, and allied subjects. Since 1928 he has been a lecturer in the University of Pittsburgh-Westinghouse graduate school plan.

D. W. Ver Planck (A'31) formerly a design engineer, General Electric Company, Philadelphia, Pa., recently was appointed assistant professor of electrical engineering at Yale University, New Haven, Conn. Mr. Ver Planck is a native (1906) of Swampscott, Mass., and received the degrees of bachelor of science (1928) and master of science (1929) at Massachusetts Institute of Technology. He entered the advanced engineering course of the General Electric Company, Schenectady, N. Y., in 1929, and received assignments to both the Schenectady and Lynn, Mass., works of that company. He was transferred to the Philadelphia works in 1935.

F. E. Johnson (A'13, F'31, director) dean of the college of engineering, University of Missouri, Columbia, has been appointed chairman of the Institute's committee on student Branches for the year 1936–37. A biographical sketch and photograph of Dean Johnson were given on page 1047 of Electrical Engineering for September 1936 in connection with his election as a director of the Institute. He has also been appointed a member of the committee on education, on which he served 1933–35, and of the committee on electrical machinery.

L. B. Bender (A'20, M'27) lieutenant colonel, signal corps, U.S. Army, formerly director of the aircraft radio laboratory, Wright Field, Ohio, has been transferred to the office of the chief signal officer, Washington, D. C., in the capacity of chief of the research and development division.

L. K. Murphy (A'29) formerly assistant purchasing agent, Brooklyn (N. Y.) Edison Company, has been appointed manager of the Bedford district office. Mr. Murphy is a 1920 electrical engineering graduate of Brown University, and entered the purchasing department of the Brooklyn Edison Company following a 2 year training course with the General Electric Company, Schenectady, N. Y.

A. R. Williams (A'31, F'35) rate specialist, Federal Power Commission, Washington, D. C., has been appointed chief of the division of rates, costs, and evaluations of the engineering bureau, Federal Power Commission. Prior to his engagement by the Federal Power Commission in 1934, Mr. Williams was identified with several consulting engineering and utility management companies.

W. R. Harry (Enrolled Student) Bell Telephone Laboratories, Inc., New York, N. Y., has been awarded the 1935 AIEE North Eastern District prize for Branch paper. Mr. Harry is a native (1912) of Detroit, Mich., and received the degree of electrical engineer at Cornell University in 1936. Following his graduation, he was engaged by the Bell Telephone Laboratories. He is a member of Sigma Xi.

G. R. Town (A'28) formerly an instructor in electrical engineering and physics, Rensselaer Polytechnic Institute, Troy, N. Y., recently accepted a position in the research department of the Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y.

E. G. Adams (A'31) formerly economist in the office of the assistant to the president, Canadian Pacific Railway Company, Montreal, Que., Canada, recently accepted a position with the consulting engineering firm of Coverdale and Colpitts, New York, N. Y.

W. J. Merchant (A'36) formerly an engineering assistant, Staten Island Rapid Transit Railway Company, Stapleton, N. Y., recently joined the technical staff of the Bell Telephone Laboratories, Inc., New York, N. Y.

G. P. Lehmann (A'35) student engineer, General Electric Company, Schenectady, N. Y., has been transferred to the high voltage engineering laboratories of the General Electric Company, at Pittsfield, Mass.

C. S. Lumley (A'23, M'29) formerly an architectural engineer for the firm of Smith, Hinchman, and Grylls, Inc., Detroit, Mich., recently accepted a position as assistant electrical engineer, Department of Public Works, Detroit.

Clinton Cater (A'27) formerly assistant engineer, Ceara Tramway, Light, and Power Company, Forteleza, Brazil, recently accepted a position with the Canadian and General Finance Company, Ltd., London, England.

F. D. Wyatt (A'15, M'21) United Light and Power Engineering and Construction Company, Davenport, Iowa, has been transferred to the Kansas City, Mo., offices of that company. Mr. Wyatt has been active in local Institute affairs in the Iowa Section.

T. A. Knabe (A'32) formerly electrical engineer-trade foreman, St. Emma Agricultural and Industrial Institute, Rock Castle, Va., now is employed by the New York and Honduras Rosario Mining Company, Rosario, San Juancito, Honduras.

W. G. Jones (A'36) recently was appointed a graduate assistant in electrical engineering at the University of Southern California, Los Angeles. Mr. Jones is a 1936 electrical engineering graduate of the University of Arizona.

J. S. Francis (A'33) formerly an instructor in electrical engineering, Michigan College of Mining and Technology, Houghton, recently accepted a position as electrical distribution engineer for the Consumers Power Company, Jackson, Michigan.

William Webber (A'33) formerly maintenance engineer, Flintkote Company, Chicago Heights, Ill., has accepted a position as power plant engineer for the Compañía Mexicana de Petroleo El Aguila, Minatitlan, Veracruz, Mexico.

L. J. Corbett (A'03, M'13) consulting electrical engineer, Berkeley, Calif., recently has published a book "Inductive Coordination," reflecting the results of his many years of study, research, and practical experience in that important field.

T. B. Jones (A'35) formerly employed by the Carbide and Carbon Chemicals Corporation, Whiting, Ind., recently accepted a position in the process development section of The Linde Air Products Company, Newark, N. J.

O. C. Falkovich (A'29) formerly assistant hydraulic engineer, City of San Francisco (Calif.) water department, recently accepted an appointment as associate mechanical engineer for the Tennessee Valley Authority, Knoxville.

H. N. Steen (A'31) formerly a laboratory assistant in the electrical engineering department, University of Washington, Seattle, now is assistant engineer for the Seattle Cedar Lumber Manufacturing Company.

L. P. Morris (A'30) formerly an automotive radio engineer for the Case Electric Corporation, Marion, Ind., recently was employed as a development engineer for the Sparks-Withington Company, Jackson, Mich.

T. L. Botterill (A'35) is employed by the Pullman Company, San Francisco, Calif., instead of Denver, Colo., as incorrectly stated in Electrical Engineering for September 1936, page 1049.

Meyer Ziev (A'34) is employed at the U.S. Navy Yard, Philadelphia, Pa. His affiliation was incorrectly listed as with the Brooklyn, N. Y., Navy Yard in Electrical Engineering for September 1936, p. 1049.

V. J. Cissna (M'30) formerly with the U.S. Engineer Corps, Kansas City, Mo., has transferred to the Tennessee Valley Authority design and construction division at Chattanooga, Tenn.

A. D. SILVA (A'17) formerly consulting engineer for the Atwater Kent Manufacturing Company, recently accepted a position as radio engineer with Noblitt-Sparks Industries, Inc., Columbus, Ind.

W. T. COOPER (A'32) who has been assistant production engineer, Schweitzer and Conrad, Inc., Chicago, Ill., now is employed by the Bakelite Corporation, Bound Brook, N. J.

E. R. NIGH (A'11, M'26) superintendent of light and power, Puget Sound Power and Light Company, Everett, Wash., has been transferred to the Seattle, Wash., offices of that company.

L. M. GROW (A'27) formerly electrical engineer for the Central Ohio Light and Power Company, Wooster, has accepted a similar position with the Southwestern Public Service Company, Amarillo, Texas.

J. D. HEIBEL (A'34) formerly a draftsman for the Hookless Fastener Company, Meadville, Pa., now is employed as a development engineer for the Erie (Pa.) Resistor Corporation.

L. G. ULM (A'35) division construction superintendent, Ohio Bell Telephone Company, Toledo, has been transferred to the Columbus offices of that company in a similar capacity.

W. L. TADLOCK (A'29) formerly associate electrical engineer, Bureau of Yards and Docks, U.S. Navy, Pearl Harbor, T. H., now is employed by the Commonwealth and Southern Corporation, Birmingham, Ala.

C. A. BROWN (A'23) formerly a sales representative for the De La Vergne Engine Company, Philadelphia, Pa., now is a sales engineer for the American Locomotive Company, Washington, D. C.

P. J. AMBROSE (A'36) formerly an electrician for the Cadillac Motor Car Company, Detroit, Mich., now is an instructor in radio engineering at Indiana Technical College, Fort Wayne.

G. W. CLOTHIER (A'36) formerly a teaching fellow, University of Washington, Seattle, now is a student engineer for the Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

J. S. ENSOR (A'26) recently resigned his position as assistant engineer, Corps of Engineers, U.S. Army, Tucumcari, N. M., to join the engineering staff of the Waterbury (Conn.) Tool Company.

E. L. CARLSON (A'36) who has been with the General Electric Company, New York, N. Y., has accepted a position with the National Electric Products Corporation, New York, N. Y.

B. F. MEADOR (A'29, M'35) formerly assistant to the chief engineer, Great Lakes Pipe Line Company, Kansas City, Mo., has joined the consulting engineering firm of Black and Veatch, Kansas City.

M. G. JOGEESE (A'30) who has been an inspector for the Electric Storage Battery Company, Brooklyn, N. Y., now is with the Philco Radio and Television Corporation, Pittsburgh, Pa.

Obituary

SAMUEL MONTGOMERY KINTNER (A'02, F'36) vice president, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., died September 28, 1936, as this issue was going to press. A biographical sketch of Doctor Kintner will appear in the November issue.

HUGH PATTISON (A'03, M'12) engineer of equipment, Third Avenue Railway Company, New York, N. Y., died August 20, 1936. Mr. Pattison was born at Cambridge, Md., August 3, 1872, and was graduated in electrical engineering from The Johns Hopkins University in 1892. In 1927 he received the degree of bachelor of science *extraordinem* from that institution. After a brief service as electrician in the equipment department of the Norfolk (Va.) Navy Yard, he became an assistant in the Baltimore offices of the consulting engineering firm of Sprague, Duncan, and Hutchinson, Ltd., in 1893. Mr. Pattison was made foreman in charge of electrical construction on the Library of Congress building, Washington, D. C., in 1894, and continued to serve in that capacity until he became associated with the Sprague Electric Company, New York, N. Y., in 1898, as a technical assistant on the electrification of various railway properties. During 1901–03 he represented Dr. Cary T. Hutchinson (A'90, F'13, Life Member) consulting engineer, New York, N. Y., as resident electrical construction engineer for the Pennsylvania Steel Company, Steelton, Pa., and from 1903 to 1905 was an engineer for Westinghouse, Church, Kerr, and Company, New York, N. Y. From 1905 to 1911 Mr. Pattison directed the electrification of the West Jersey and Seashore Railway Company properties and supervised the construction of the Pennsylvania Railroad from Manhattan terminal through the New York terminal to the Sunnyside yards. From 1911 to 1915 he was electrical engineer of the Smoke Abatement and Electrification of Railway Terminals Committee of the Chicago Association of Commerce. During 1915–19 he was with the Eddystone Rifle Plant as electrical engineer and assistant to the general manager. In 1921–22 he served as electrical engineer of the Illinois Railroad Electrification Commission and in 1923 joined the Virginian Railway Company, Norfolk, Va., as electrical engineer during construction and subsequent operation. Mr. Pattison became associated with the engineering staff of the Third Avenue Railway Company in 1933. He was a member of the American Society of Mechanical Engineers and American Society of Civil Engineers.

HARRY WILLIAMS FULLER (A'03) vice president in charge of engineering and construction, Byllesby Engineering and Management Corporation, Chicago, Ill., died August 28, 1936. Mr. Fuller was born June 14, 1868, at New York, N. Y., and was graduated from Rutgers College in 1891. Following his graduation, he was employed briefly by the Field Engineering Company, New York, N. Y., and the General Electric Company before associating himself with the Consolidated Traction Company, Jersey City, N. J., in 1894. He remained with that company and its successor, the Northern New Jersey Street Railway Company, as superintendent and assistant general manager, until 1901. At that time he became general manager of the Washington (D. C.) Railway and Electric Company and the Potomac Electric Power Company, where he remained until he joined the Byllesby Engineering and Management Corporation in 1911 as vice president and general manager of the Appalachian Power Company, Bluefield, W. Va. After a brief service as vice president of the Louisville (Ky.) Gas and Electric Company, Mr. Fuller was transferred to the Chicago offices of the Byllesby Company in 1913, remaining there until he was made vice president in charge of operation of the Northern States Power Company in 1918. He held that position until 1924, when he was elected vice president in charge of engineering and construction for the Byllesby Company. In addition, he was a vice president and director of the Standard Gas and Electric Company and a director of Standard Power and Light Corporation, Northern States Power Company, Duquesne Light Company, and Louisville Gas and Electric Company.

ALFRED ALSAKER (A'09) chief engineer, Delta-Star Electric Company, Chicago, Ill., was killed in an accident at Long Beach, N. Y., August 3, 1936. Mr. Alsaker was born October 14, 1884, at Bergen, Norway, and was graduated in electrical and mechanical engineering from the Bergen Technical College in 1904. He served as draftsman and inspector for Algemeine Elektricitäts Gesellschaffts, Bergen, briefly before coming to the United States in 1905 to join the engineering staff of the Western Electric Company, Chicago. In the same year he accepted a position as draftsman for the Commonwealth Edison Company, Chicago, and in 1908 was transferred to the North Shore Electric Company, where he was advanced to chief draftsman and later to engineer of station design. Mr. Alsaker resigned from the North Shore Electric Company to affiliate himself with the Delta-Star Company in 1916. He recently completed a book "The Capitalistic System and the Nature of Unemployment," in which the subject is treated in an engineering and mathematical manner. He was a member of the Norwegian-American Engineering Society.

HAMILTON MCRARY JONES (A'10, M'14) general manager, International Power Company, Ltd., Montreal, Que., Canada, died August 12, 1936. Mr. Jones was born at Warrenton, N. C., August 20, 1883, and received the degree of bachelor of arts in electrical engineering at the University of North Carolina in 1905. Immediately following his graduation, he was employed by the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., first as an apprentice engineer and later as a road erecting engineer in the New York, N. Y.,

district office. In 1907 he was appointed assistant chief electrical engineer of Guanica Centrale, Ensenada, Porto Rico, where he remained until he was made chief electrical engineer of Central Fortuna, P. R., in 1910. Mr. Jones was appointed assistant superintendent of the lighting division of the Porto Rico Railway, Light, and Power Company in 1911 and was promoted to superintendent in the following year, concurrently serving as consulting electrical engineer for the Government of Porto Rico Irrigation Service until 1916. He was sent to Japan in 1916 to serve as representative for the Westinghouse Electrical Export Company in Tokyo, but returned to the United States in 1919 as an engineer for the Westinghouse Electric International Company, Denver, Colo. Mr. Jones was transferred to the New York, N. Y., offices of that company in 1920 as foreign sales engineer; in 1922 he was designated special representative and in 1923 manager of the department of the Americas, in which capacity he served until he joined the International Power Company in 1929.

William King Hale (A'17, M'26) assistant transmission and protection engineer, Mountain States Telephone and Telegraph Company, Denver, Colo., died in December 1935, according to word just received at Institute headquarters. Mr. Hale was born January 12, 1889, at West Point, N. Y., and attended Purdue University and the University of Colorado. Following a 3-year training period in maintenance of telephone exchanges, he was employed in 1916 by the Mountain States Telephone and Telegraph Company as supervisor of the operation of telephone storage batteries. In 1919 Mr. Hale was placed in charge of a special investigation of ground potentials in Montana and subsequently was designated as division electrical engineer for the states of Utah, Idaho, and Colorado. He was appointed state electrical engineer in 1925, with offices at Denver, Colo., where he remained continuously; however, he was appointed assistant transmission and protection engineer in 1935.

Harry Bates Thayer (A'07) former president and chairman of the board of the American Telephone and Telegraph Company, New York, N. Y., died September 3, 1936. Mr. Thayer was born at Northfield, Vt., August 17, 1858, and received the degree of bachelor of arts at Dartmouth College in 1879. Following a brief association with the Central Vermont Railroad Company, Bellows Falls, he joined the engineering staff of the Western Electric Company, Chicago, Ill., in 1881. Mr. Thayer was transferred to the New York, N. Y., offices of that company as manager in 1883, and in 1902 was made vice president. In 1907 he was made general manager, and in the following year was promoted to the presidency. He was appointed vice president of the American Telephone and Telegraph Company in 1909, and held that position for 10 years before becoming president in 1919. In 1925 Mr. Thayer relinquished the presidency to accept the chairmanship of the company. Upon reaching the retirement age in 1928, his resignation was accepted and his position was discontinued.

William Hugh Ross Fraser (A'12) general manager, Mexican Light and Power Company, Mexico City, shot by an assassin, died August 27, 1936. Mr. Fraser was born December 23, 1883, at Alvah, Banff, Scotland, and attended the Glasgow Technical College. Following a preliminary training period with the Electrical Construction Company, Wolverhampton, England, he went to Canada to become an engineer for the Hydro-Electric Power Commission of Ontario in 1910. He served in the Vancouver, B. C., offices of the General Electric Company from 1912 until he was appointed electrical superintendent of the British Columbia Electric Railway Company, Vancouver, in 1914. Mr. Fraser remained with that company until 1920, when he became associated with the Mexican Light and Power Company as an electrical engineer. He was made general manager in 1924.

Elam Miller (A'05, M'13) staff engineer, American Telephone and Telegraph Company, New York, N. Y., died September 2, 1936. Mr. Miller was born July 14, 1881, at San Francisco, Calif., and after receiving his formal education was employed by the Pacific Telephone and Telegraph Company, San Francisco, in 1898. His work with that company comprised cable testing, materials testing research, and systems improvement research. He accepted a position with the American Telephone and Telegraph Company in 1912, and was transferred to New York, N. Y., as transmission engineer. He was later transferred to the office of the executive vice president and has since held the position of staff engineer of that company.

Adolf John Lobeck (A'20, M'21) superintendent of distribution, The New York (N. Y.) Edison Company, died June 25, 1936. Mr. Lobeck was born August 5, 1891, at New York, and attended the Polytechnic Institute of Brooklyn, N. Y. He entered the employ of The New York Edison Company in 1909, and except for a brief period (1917–18) during which he was engaged in U.S. Government work, served that company continuously. Mr. Lobeck held successively the positions of service foreman, engineer, assistant district superintendent, assistant superintendent of operation, district superintendent, and superintendent of distribution.

Joseph David Israel (A'09, M'13) district manager, Philadelphia (Pa.) Electric Company, died June 15, 1936. Mr. Israel was born at Philadelphia, February 28, 1868, and received the degrees of bachelor of science (1886) and mechanical engineer (1887) at the University of Pennsylvania. Immediately following his graduation, he was employed by the Edison Electric Light Company of Philadelphia as superintendent of street lighting; later he became successively assistant manager, secretary, and manager. Mr. Israel became district manager of the Philadelphia Electric Company in 1904 and held that position continuously for 32 years.

Membership

Recommended for Transfer

The Board of Examiners, at its meeting on September 23, 1936, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Mahood, Edwin T., engineer, Southwestern Bell Telephone Company, Kansas City, Mo.
Meyer, Frank J., vice president in charge of operation, Oklahoma Gas and Electric Company, Oklahoma City.
Sibley, Edgar D., vice president, E. M. Gilbert Engineering Corporation, Reading, Pa.

3 to Grade of Fellow

To Grade of Member

Betzer, Cecil E., cable specification research engineer, Commonwealth Edison Company, Chicago, Ill.
Chopra, H. C., executive engineer, electrical department, Trivandrum, Travancore State, India.
Cornell, E. S., chief engineer, Delta-Star Electric Company, Chicago, Ill.
Davis, L. L., electrical engineer, Kansas City, (Mo.) Public Service Company.
Hessler, V. P., instructor in electrical engineering, Iowa State College, Ames
Higgins, R., development engineer, Ohio Brass Company, Barberton, Ohio.
Luce, D. C., general superintendent of generation, Public Service Electric and Gas Company, Newark, N. J.
Lunas, L. J., electrical engineer, Westinghouse Electric and Manufacturing Company, Newark, N. J.
Mackey, C. M., manager, Westinghouse Electric Supply Company, Oklahoma City, Okla.
McDonald, R., chief electrician of construction, Cerro de Pasco Copper Corporation, Malpaso, Peru.
Miille, R. R., design engineer, Westinghouse Electric and Manufacturing Company, Springfield, Mass.
Ogden, H. S., electrical engineer, General Electric Company, Erie, Pa.
Rogoff, J. A., inspector, division of engineering Department of Hospitals, New York, N. Y.
Schamberger, S. O., hydraulic engineer, New York Power and Light Corporation, Albany, N. Y.
Smith, C. E., assistant engineer, Brooklyn (N. Y.) Edison Company.
Storms, C. A., electrical engineer, Michigan Limestone and Chemical Company, Rogers City.
Tapy, R. W., instructor of electrical engineering, University of Detroit, Mich.
Tebo, J. D., member of technical staff, Bell Telephone Laboratories, Inc., New York, N. Y.
Tuck, F. W., electrical mechanical superintendent, Benguet Consolidated Mining Company, Antamok, Philippine Islands.
Van den Meersche, A. J., instructor, University of Ghent, Belgium.
Waddell, J. J., electrical engineer, engineer of works and town engineer, Borough Council of San Fernando, Trinidad, B. W. I.
Watts, R. S., load dispatcher, Commonwealth Edison Company, Chicago, Ill.
Witherow, H. M., designing engineer, General Electric Company, Fort Wayne, Ind.
Young, D. S., district engineer, Anaconda Wire and Cable Company, Chicago, Ill.

24 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Oct. 31, 1936, or Dec. 31, 1936, if the applicant resides outside of the United States or Canada.

Bean, G. W., Texas Electric Service Company, Ft. Worth, Texas.
Blakey, A. B., P. O. Box 131, Great Neck, L. I., N. Y.
Cauthen, W. C. (Member), Camp Lisenby, CCC, North Fork, Calif.
Cleaver, O. P., Westinghouse Lamp Company, Bloomfield, N. J.
Croney, S. I., Keystone Pipe Line Company, Philadelphia, Pa.
Dailey, H. J., Westinghouse Lamp Company, Bloomfield, N. J.
Daus, G. A., Public Service Company of Northern Illinois, Chicago.

Dickinson, H. F., Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y.
Dolle, A. R., Brooklyn (N. Y.) Edison Company, Inc.
Flaherty, G. H., Brooklyn (N. Y.) Edison Company, Inc.
Fosterling, A. W., Eastern Oregon Light & Power Company, Haines, Ore.
Fraser, W. (Member), Aluminum Company of Canada, Arvida, P.Q., Canada.
Glick, H. S., Warner Brothers Pictures, New York, N. Y.
Gussett, N. B. (Member), San Antonio Public Service Company, Texas.
Hartmann, F., Brooklyn (N. Y.) Edison Company, Inc.
Hayden, W. Jr., New York (N. Y.) Edison Company, Inc.
Hays, W. G., Aluminum Company of America, San Francisco, Calif.
Israel, A. I., 112 Callender St., Dorchester, Mass.
Jeffries, Z. (Member), General Electric Company, Cleveland, Ohio.
Johnston, L. E., U.S. Army Engineers, Fort Peck, Mont.
Leightman, H., R. R. 3, Box 1030, Memphis, Tenn.
McIlroy, M. S. (Member), Central Hudson Gas & Electric Corporation, Beacon, N. Y.
Maddrey, W. D., Texas Electric Service Company, Wichita Falls, Texas.
McMahon, R. L., Jr., U.S. Engineer Office, Providence, R. I.
McSherry, J. J., Brooklyn (N. Y.) Edison Company, Inc.
Miller, C. B., Brooklyn ((N. Y.) Edison Company, Inc.
Miller, R. C., American Gas & Electric Company, New York, N. Y.
Moser, H. J., American Machines & Metals Manufacturing Corporation, New York, N. Y.
Odell, L. T., Bell Telephone Laboratories, Inc., New York, N. Y.
Pollard, A. L. (Member), 514 21st St., Knoxville, Tenn.
Pond, A. L. (Member), General Electric Company, Milwaukee, Wis.
Raines, W. A., General Electric Company, New York, N. Y.
Reilly, E. P., Brooklyn (N. Y.) Edison Company, Inc.
Renking, H. L., 208 North Broadway, St. Louis, Mo.
Rockfield, M. L., Aluminum Company of America, Alcoa, Tenn.
Rummel, E. T., Hertner Electric Company, Cleveland, Ohio.
Ruth, E. S. (Member), Edwards & Company, Inc., New York, N. Y.
Sheldon, H. C., Burndy Engineering Company, New York, N. Y.
Smith, A. B., Brooklyn (N. Y.) Edison Company, Inc.
Sukachoff, A., physics department, Memorial Hospital, New York, N. Y.
Sturdy, W. W., Bell Telephone Laboratories, Inc., New York, N. Y.
Thomas, J. W., Potomac Electric Power Company, Washington, D. C.
Thrasher, M. J., Texas Power & Light Company, Dallas.
Tincombe, H. F., International Nickel Company, Copper Cliff, Ont., Canada.
Wiber, A. P., 48 Abbott Ave., Danbury, Conn.
Witzler, H. F. (Member), American Telephone & Telegraph Company, New York, N. Y.
Woodcock, V. E., c/o C. D. Ehret, Philadelphia, Pa.

47 Domestic

Foreign

Antill, A., British Municipal Council Tientsin, China
Christiansen, K. A. (Fellow), Administration of Danish Posts & Telegraphs, Copenhagen V, Denmark.
Ewart, S. J. M. (Member), Hutt Valley Electric Power Board, Belmon, Lower Hutt, N. Z.
Franklin, R. J., General Electric Company, Witton, England.
Gangoli, N. (Member), Calcutta Ignition Company, India.
Kissel, F. T. M. (Member), Public Works Department, Wellington, New Zealand.
Nariman, P. H., Volkart Brothers, Bombay, India
Thomson, P. R., Power Station, Colenso Natal, South Africa.

8 Foreign.

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Brown, J. Carleton, 334 Parkway Drive, Atlanta, Ga.
Bukley, E. J., Malaja-Dmitrovka D. 8 Kv. 38, Moscow, U.S.S.R.
Burns, Arthur E., 1958 E. 29th St., Brooklyn, N. Y.
Collins, Ogie B., Minimum, Mo.
Dean, George, Queen Victoria Bldg., Sydney, N.S.W., Aust.
Eiler, E. E., 101 Brookline Court, Upper Darby, Pa.
Godoy, Ernesto R., Cia. Tel. y Tel. Mex., 16 de Septiembri No. 13, Mexico, D.F., Mex.
Jones, Harry Kenneth, 5511 Kenmore Ave., Chicago, Ill.
Koch, Joseph Stanley, 11 Howe Ave., New Rochelle, N. Y.
Ludwig, Leon R., 434 Burling Road, Forest Hills, Pittsburgh, Pa.
Luther, Herbert A., 50 Atwood Ave., Johnston, R. I.
Megeath, S. A., Jr., 14 North Ave., Elizabeth, N. J.
Millheisler, Charles A., 1417 Catalpa Ave., Chicago, Ill.
Miyota, Nath S., 916½ Howell St., Seattle, Wash.
Pollastro, John B., Helper, Utah.
Ridenhour, W. L., 216 Vance St., Chapel Hill, N. C.
Sawyer, Fred E., 811 E. Wisconsin Ave., Milwaukee, Wis.
Walstra, W. G., Y. M. C. A., Boise, Idaho.
Willson, William H., Jr., 1720—2nd Ave., Cedar Rapids, Iowa.
Wong, Harry Y. L., 771 Broadway, West New York, N. J.

20 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

DIESEL ELECTRIC PLANTS. By E. J. Kates. Chicago, American Technical Society, 1936. 181 p., illus., 9x6 in., cloth, $2.00. A brief, practical, nonmathematical presentation of the characteristics of the Diesel engine and the principles of Diesel driven electric generators. Voltage regulation, parallel operation, governing, and automatic operation are considered. A chapter is devoted to Diesel locomotives.

ENGINEERING VALUATION. By A. Marston and T. R. Agg. N. Y. and London, McGraw-Hill Book Co., 1936. 655 p., illus., 9x6 in., cloth, $6.00. Sets forth the basic principles of the valuation of industrial properties and illustrates their application by specific examples. Includes synopsis of all decisions of the United States Supreme Court that affect the practice of valuation and develops a new principle of depreciation.

Introduction to the THEORY of LINEAR DIFFERENTIAL EQUATIONS. By E. G. C. Poole. Oxford, England, Clarendon Press; N. Y., Oxford University Press, 1936. 202 p., illus., 10x6 in., cloth, $6.00. Designed for students that have had an elementary course in differential equations.

CLASS BOOK of MAGNETISM and ELECTRICITY. By H. E. Hadley. Lond. and N. Y. Macmillan and Co., 1936. 512 p., illus., 8x5 in., cloth, $2.50. A textbook for secondary schools which emphasizes fundamental principles and presents some of the history of the subject and its pioneer developments.

MEN of SCIENCE. By J. G. Crowther. N. Y., W. W. Norton and Co., 1936. 332 p., illus., 9x6 in., cloth, $3.50. Contains biographies of English physicists, including Davy, Faraday, Joule, Thomson, and Maxwell.

MODERNE STAHLGIESSEREI für Unterricht und Praxis. By B. Osann. Berlin, Julius Springer, 1936. 261 p., illus., 10x7 in., lea., 26.70 rm. Includes an account of the crucible, open hearth, small converter, arc, and induction furnace processes of steel manufacture.

D-C VOLTAGE DISTRIBUTION in RADIO RECEIVERS. By J. F. Rider. N. Y., John F. Rider, 1936. 96 p., illus., 8x6 in., paper, $0.60. Presents d-c theory and discusses the 3 d-c circuits used in radio receivers.

FRONTIERS of SCIENCE. By C. T. Chase. N. Y., D. Van Nostrand Co., 1936. 352 p., illus., 9x6 in., cloth, $3.75. Reviews progress in astronomy and astrophysics, atomic physics and physical chemistry. Intended for the general reader.

DIELECTRIC PHENOMENA in HIGH VOLTAGE CABLES. (Monographs on Electrical Engineering, v. 3). By D. M. Robinson and P. V. Hunter. Lond., Chapman and Hall, 1936. 173 p., illus., 9x6 in., cloth, 15s. Deals with the performance of the dielectric in a cable, and the way in which performance may be affected by construction.

NATIONAL PHYSICAL LABORATORY, REPORT for the YEAR 1935. Lond., Dept. of Scientific and Industrial Research, 1936. 249 p., illus., 11x8 in., paper, 12s. (Obtainable from British Library of Information, N. Y., $3.25.) Contains a review of the investigations in the fields of physics, electricity, and engineering that were carried on by the laboratory during 1935.

A.T.M.-Archiv für technisches Messen. Lieferungen 50–58. Munich and Berlin, R. Oldenbourg, August 1935–April 1936. Illus., 12x8 in., paper, 1.50 rm. Provides a survey of information on engineering measurements and new instruments.

ELEMENTARY MECHANISM. By P. K. Slaymaker. N. Y., D. Van Nostrand Co., 1936. 181 p., illus., 9x6 in., cloth, $2.25. Intended for students in engineering colleges. Discusses fundamental principles with their applications, developing the subject from elementary concepts and analyzing the material in a logical order.

ELEMENTARY PLANE SURVEYING. By R. E. Davis. N. Y. and Lond., McGraw-Hill Book Co., 1936. 424 p., illus., 8x5 in., lea., $3.00. Designed to meet the requirements of such short courses as those ordinarily given to students of electrical and mechanical engineering.

GRAPHIC METHODS for PRESENTING BUSINESS STATISTICS. By J. R. Riggleman, with introduction by M. C. Rorty. 2 ed. N. Y. and Lond., McGraw-Hill Book Co., 1936. 259 p., illus., 9x6 in., $2.50. A practical guide to the making of business charts. Construction of the common forms of statistical charts is explained, and the merits of specific types are described.

An INTRODUCTION to the THEORY of ELASTICITY for Engineers and Physicists. By R. V. Southwell. N. Y., Oxford University Press, 1936. 509 p., illus., 10x7 in., cloth, $10. Aims to bridge the gap between elementary texts and the books of Love and Raleigh.

LIVING TOGETHER in a POWER AGE. By S. S. Wyer. N. Y., Association Press, 1936. 231 p., illus., 10x6 in., cloth, $2.50. Presents a discussion of the economic confusion of today, attempts to point out its causes, and offers a plan for economic recovery.

ORGANIZATION and MANAGEMENT of a BUSINESS ENTERPRISE. By K. D. Fernstrom, R. F. Elder, W. P. Fiske, A. A. Schaefer, and B. A. Thresher. N. Y. and Lond., Harper and Brothers, 1935. 703 p., illus., 9x6 in., cloth, $4.25. Intended as an introductory course in business management. Primary consideration is given to the management of manufacturing enterprises.

STRUCTURE of METALS and ALLOYS. (Institute of Metals Monograph and Report Series No. 1.) By W. Hume-Rothery. Lond., Institute of Metals, 1936. 120 p., illus., 9x6 in., cloth, 3s. 6d. Reviews the work of the last 15 years on fundamental principles of crystal structure. Includes discussions of the electronic background of metallurgy, the crystal structure of the elements, and the atomic radii of the elements.

Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a cooperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

Transformers for Boulder Dam.—Four additional large power transformers have recently been purchased from the Westinghouse Electric & Mfg. Co. for the Boulder Dam Power Project. They will supply power to the Metropolitan Water District of Southern California and are rated 55,000 kva each, single phase, 60 cycles, water cooled for stepping up from 16,500 volts to 230,000 volts. These transformers will take power from generator units No. 5 and No. 6, stepping it up to 230,000 volts, at which voltage it will be transmitted to the aqueduct pumping plants of the Metropolitan Water District of Southern California, a distance of approximately 237 miles. After installation, the transformers will be operated with the neutrals of the high voltage windings solidly grounded, but they are designed so that the neutrals can have a current limiting reactor installed later if it is so desired. Total weight of each transformer after installation will be approximately 125 tons.

General Cables Appoints Sales Manager.—According to a recent announcement the General Cable Corporation has appointed Howard E. Eagleston, formerly Pacific district manager, as general sales manager with headquarters at 420 Lexington Ave., New York, effective September 1.

Aerovox License for Australia.—The appointment and licensing of the Continental Carbon Co. Pty. Ltd. of Melbourne, Australia, as manufacturers of electrolytic and other condensers under Aerovox patents and using Aerovox production methods, is announced by Aerovox Corporation of Brooklyn, N. Y. The Australian concern will duplicate those units of the Aerovox line of condensers which are required by their trade. Fred W. Clarke, managing director of the Continental Carbon Co., has been spending the past two months in the Aerovox plant, studying the manufacture of condensers with a view to setting up similar production facilities in Australia.

New Trade Name for Steel Alloys.—Announcement of the new trade name "USS Carilloy" to identify alloy steels produced by Carnegie-Illinois Steel Corp. has been made by this subsidiary of the United States Steel Corp. The name does not signify a new product, nor does it apply to any single alloy steel. It is simply a new trade designation which will serve as a quality trademark for the entire group of well-known alloy steels previously marketed as "Carnegie-Illinois Alloy Steels."

Lightweight, Pocket-Size Instruments.—A complete new line of pocket-size voltmeters, ammeters, and milliammeters, which is designated type AS-5 and supersedes the type AS-3 has been announced by, the General Electric Co. The instruments incorporate a new kind of element with higher torque and improved characteristics. The over-all dimensions of the standard unit are $5^1/_2$ inches by $3^1/_2$ inches by 2 inches, and the weight is only 12 ounces. All the instruments have an accuracy of one per cent of full scale value; have magnetic damping, a Permaloy moving vane, and are shielded from stray magnetic fields. All have a knife-edge pointer and a mirror scale for accurate reading. On the double- and triple-scale instruments, a convenient switch on the face makes it possible to change ratings without removing or rewiring terminal connections.

Trade Literature

Transformers.—Bulletin 2172A, 8 pp., "Outage-Free High Voltage Distribution Transformers." Describes an improved distribution transformer especially designed for rural service. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Control-Distribution Equipment.—Catalog, 84 pp. Describes safety switches and a wide variety of switch fuse centers; lighting panels; distribution panels and cabinets. Bull Dog Electric Products Co., Detroit, Mich.

Circuit Breakers.—Catalog 5—Section 3. Describes the new type BD air circuit breakers; 600 amperes and below; 600 volts a-c; 750 volts d-c; live or dead front, steel enclosed. The interrupting rating of this breaker is 40,000 amperes and 600 volts. Roller-Smith Co., 233 Broadway, New York.

Voltmeters.—Bulletin 436. Describes a new line of round chart recording voltmeters and ammeters for electric utilities and industrial plants. Models for wall, switchboard, flush panel, and pole mounting, as well as for portable use are illustrated. A detailed description is included of the new inverted type replaceable movement and of the novel design of the pen arm. The Bristol Co., Waterbury, Conn.

Capacitors.—Bulletin 3388, 16 pp., "Permittors for Distribution Circuits." Describes the Permittor, a capacitor in which compressed nitrogen in combination with dry condenser paper is used as the dielectric medium. The Permittor tank and terminals are hermetically sealed so that the initial gas charge is permanent. Reactive power and its effects are discussed and the advantages of Permittors over synchronous condensers are tabulated. Products Protection Corp., New Haven, Conn.

Radio and Laboratory Equipment.—Catalog J, 172 pp. Describes a wide range of apparatus applicable in broadcasting and receiving; for laboratory and industrial application. Chapters are devoted to industrial devices including the stroboscope, color comparator, sound level meter and Variac (for voltage control); resistors, condensers; inductors; frequency- and time-measuring devices; oscillators; amplifiers; bridges and accessories; standard-signal generators; oscillographs, cameras, and analyzers; meters; power supplies; and parts and accessories. General Radio Co., 30 State St., Cambridge, Mass.

Switches and Fuse Mountings.—Bulletin 32-C, 48 pp. Describes a complete line of outdoor disconnecting switches, fuse mountings and combination units in voltages up to 161 kv. All dimensions, insulator flashovers, and cantilever strengths are given. The fuse section includes recommendations for transformer protection and charts for determining blowing time of fuses for predetermined short-circuit values. Potential transformer resistors, terminal lugs, cross arm hangers, fuse tongs, hook sticks and pipe fittings are also included. Catalog numbers, dimensions and data are arranged for easy reference. A complete price list accompanies the bulletin. Delta-Star Electric Co., 2400 Block, Fulton St., Chicago, Ill.

Micromax Electric Control.—Catalog N-00A, 8 pp., "Micromax Electric Control for Proportioning Input to Demand." This newly-designed control, for the automatic regulation of a variety of quantities, can be used to provide a frequency source of high time-keeping accuracy. An electrical differential is used to check continuously the output frequency of a motor generator set against a frequency standard, such as an L & N dynamic type tuning fork. This operates through the Micromax electric control to maintain time differential within one or two tenths of a second of zero, and permits combining a tuning fork of high accuracy, but low power output, with an MG set having large power output, but low inherent time-keeping accuracy, to provide a frequency source having large power output of high accuracy. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.

Circuit Tester.—Bulletin IN.1/B. Describes a new a-c/d-c circuit tester for the communication field. The instrument is designed for the measurement of a-c and d-c voltage, a-c and d-c mills and ohms, and weighs only 14 ounces, enclosed in a polished Bakelite case. It has a scale length of $2^1/_2$ inches and knife edge pointer giving accurate readings. There are 5 a-c voltage scales: 0–15, 0–150, 0–300, 0–450, and 0–600 volts. Six d-c voltage ranges are: 0–3, 0–15, 0–150, 0–300, 0–450, and 0–600 volts. The a-c milliampere range is 0–1 mill, and the d-c milliampere ranges are: 0–1, 0–7.5, 0–30, 0–150, and 0–750 milliamperes. Resistance ranges are 0–50,000, 0–150,000, 0–750,000 ohms, and 0–7.5, 0–15, 0–30 megohms. A clearly marked rotary switch is fitted at the front for range selection making the instrument extremely simple to operate. The terminals of the instrument are of the socket type; connections are made by means of a pair of leads fitted with substantial plugs at one end and removable clips at the other. Ferranti Electric, Inc., 30 Rockefeller Plaza, New York.